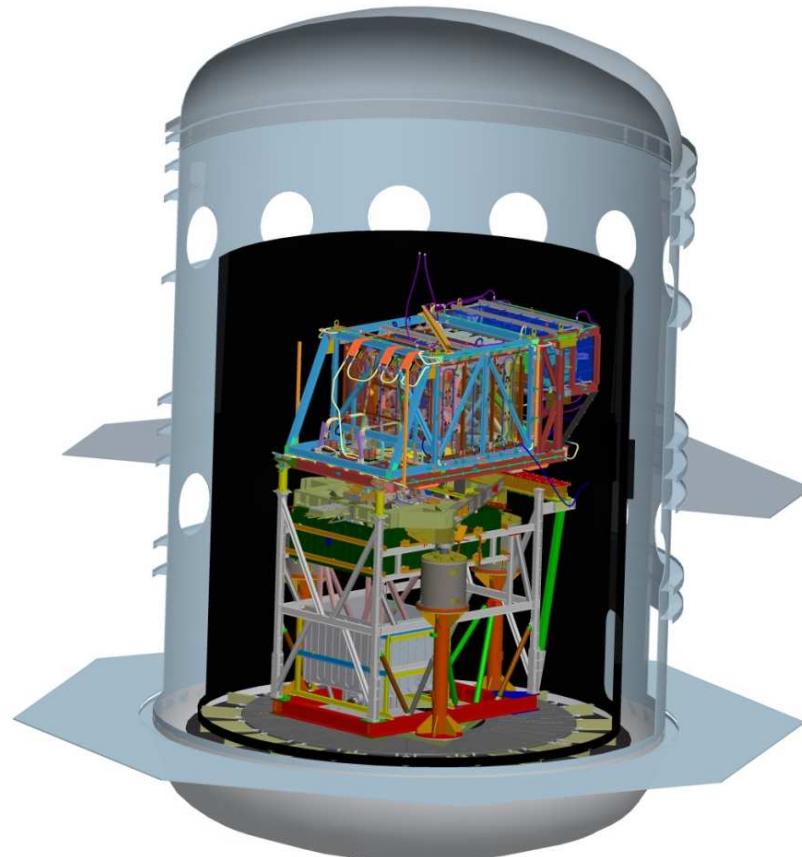


James Webb Space Telescope (JWST) Integrated Science Instrument Module (ISIM) Cryo-Vacuum (CV) Test Campaign Summary

Presenter:
Calinda Yew

Other Co-Authors:
Paul Whitehouse
Yan Lui
Kimberly Banks

29th Space Simulation Conference
NASA Goddard Space Flight Center
(GSFC)



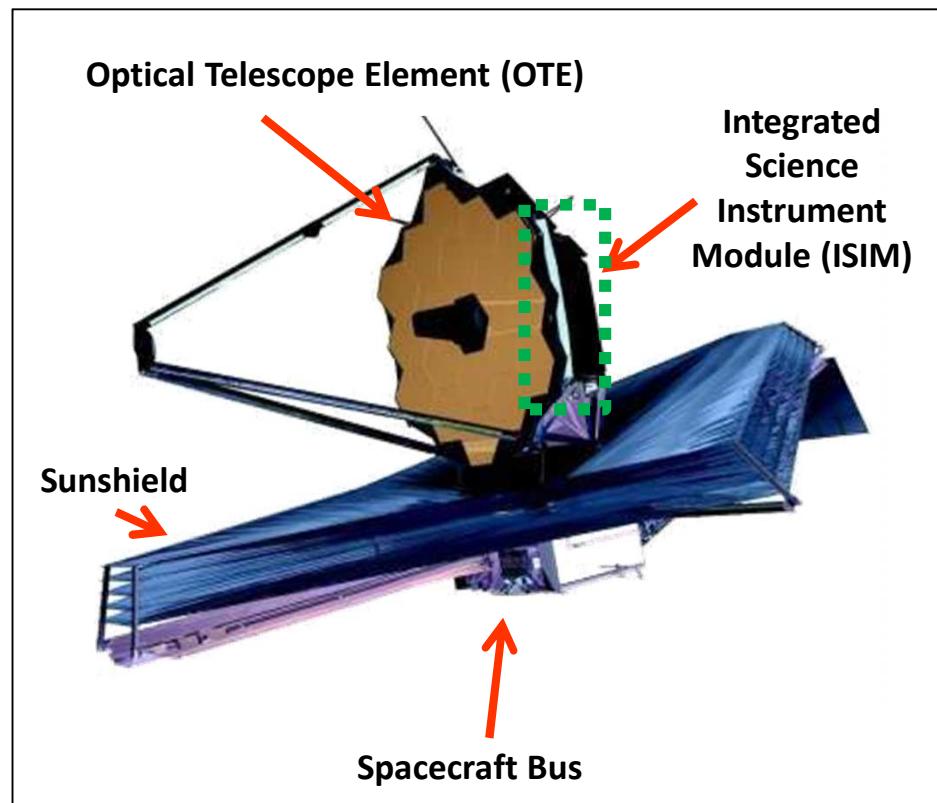
Agenda

- JWST Mission Overview
- CV Test Objectives
- Test Configuration Overview
- Test Requirements
- CV Overall Test Summaries
- Chamber Performance
- Instrumentation Performance / Improvements
- Lessons Learned



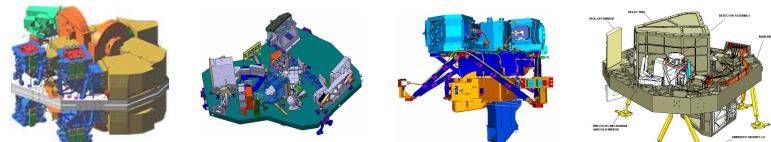
JWST Mission Overview

The Integrated Science Instruments Module (ISIM) houses all the science instruments for the James Webb Space Telescope (JWST)



JWST Mission Objective

Study the origin and evolution of galaxies, stars & planetary systems:
Optimized for infrared observations (0.6 – 28 μ m)



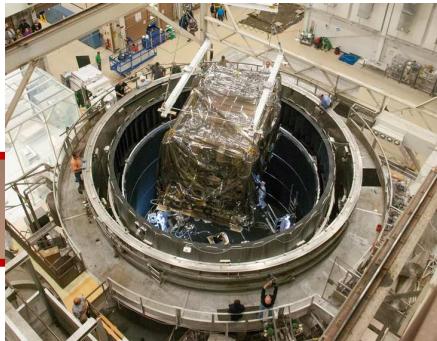
Four Science Instruments (ISIM)

- Near Infrared Camera (NIRCam)
- Near Infrared Spectrograph (NIRSpec)
- Mid-Infrared Instrument (MIRI)
- Fine Guidance Sensor (FGS)



CV Test Objectives Summary

CV1 & CV2



CV1: Risk Reduction
CV2: Assess ISIM config &
start system-level verification



CV3



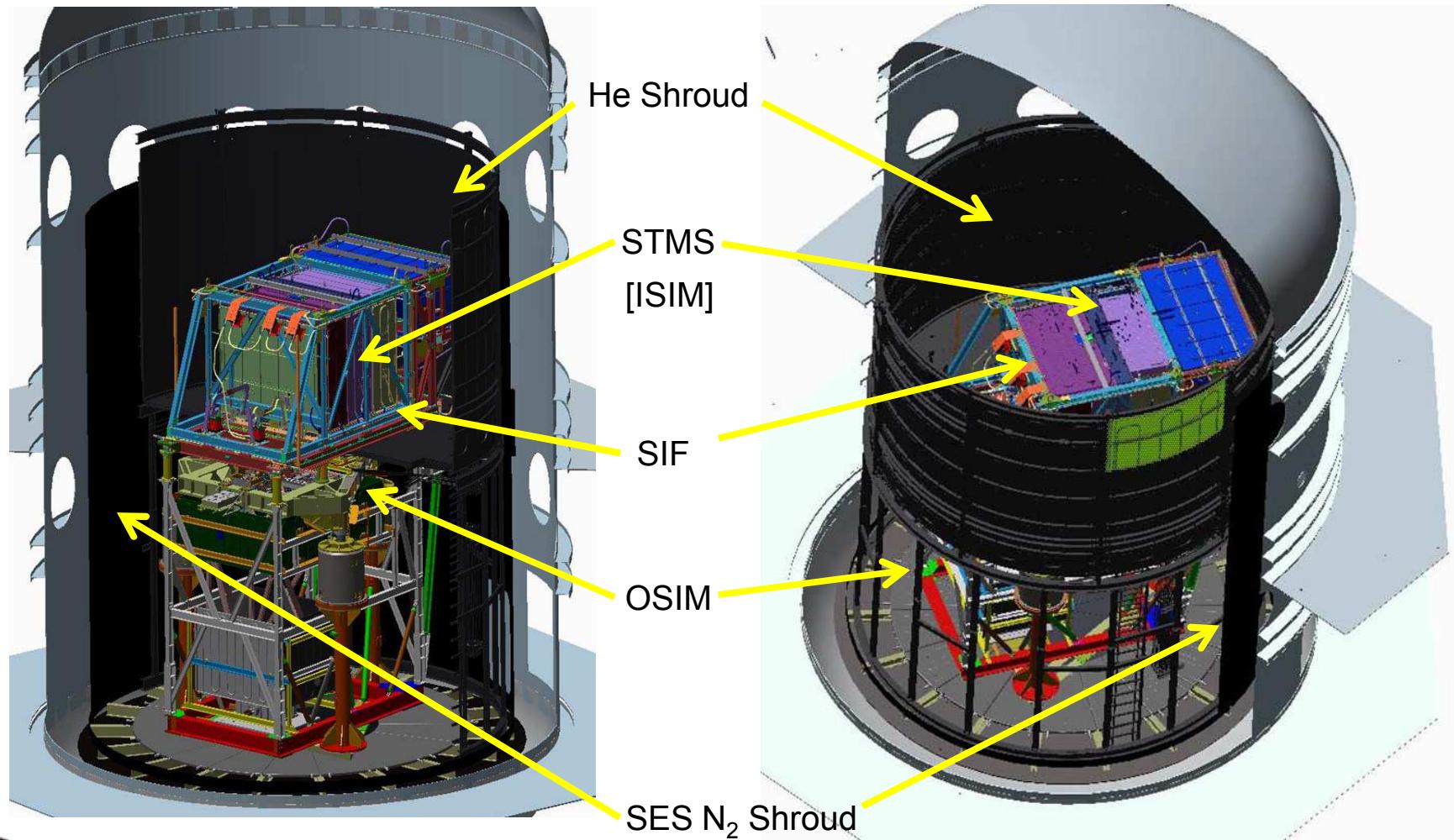
CV3: Verify ISIM in its final
configuration after
environmental exposure and
provide a post-environmental
performance baseline
(including critical ground
calibrations for science data
processing in flight)



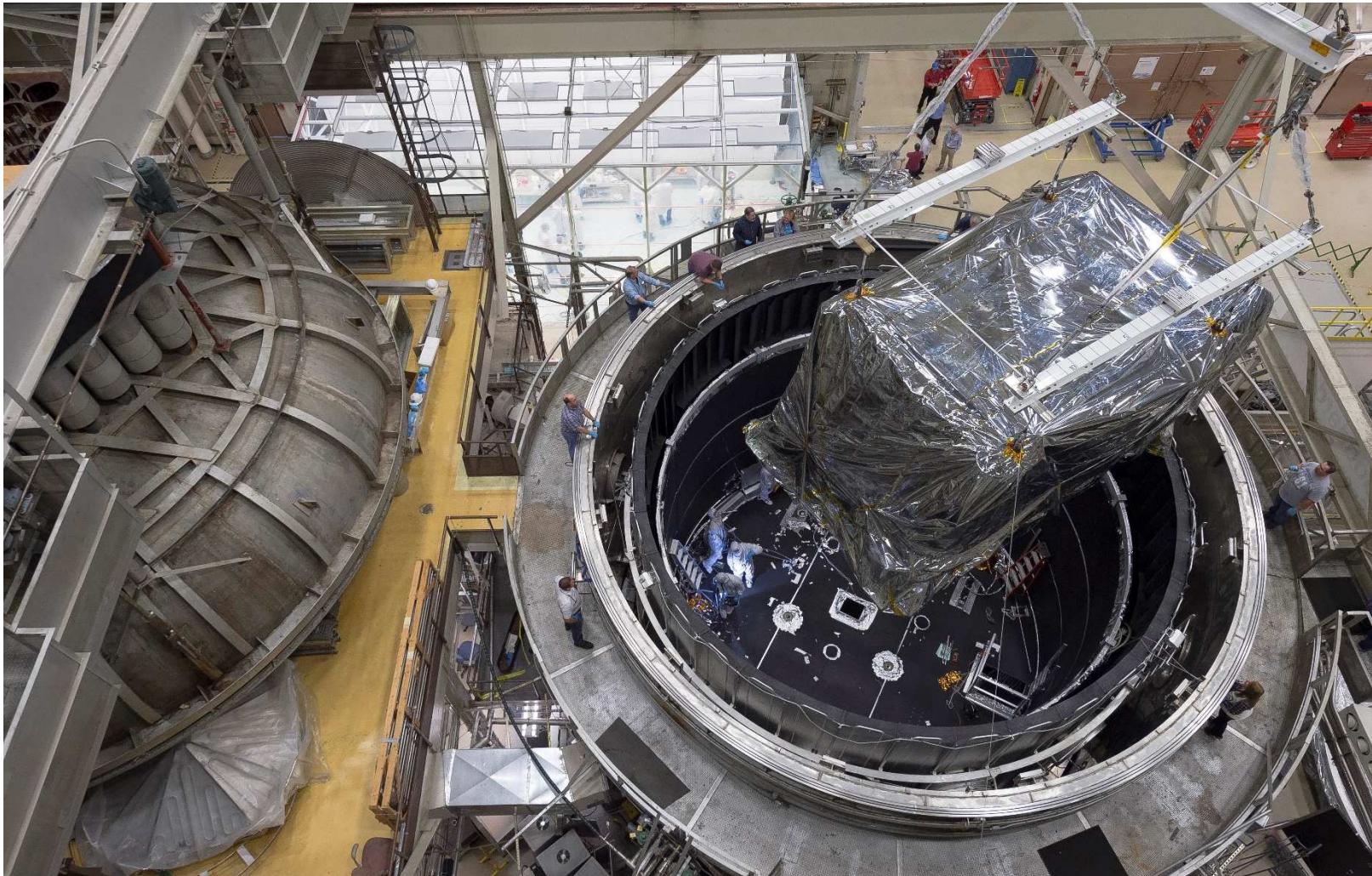
OTIS I&T
Oct 2018
Launch



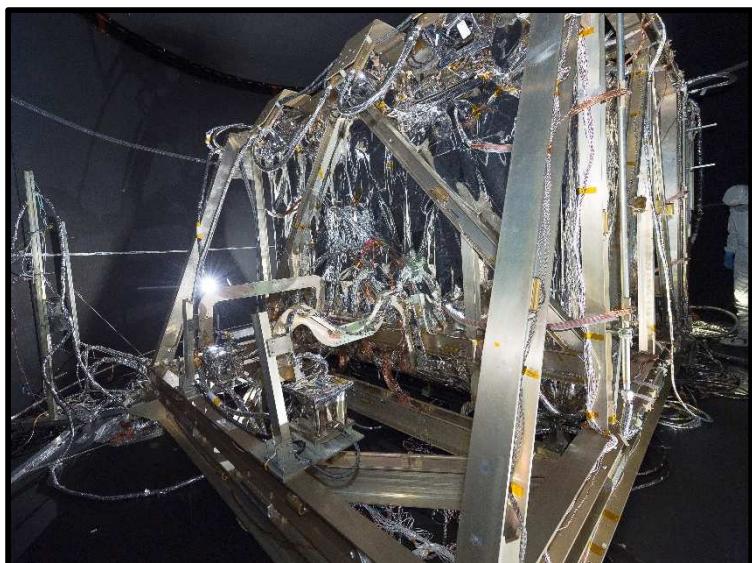
ISIM CV Testing Test Configuration



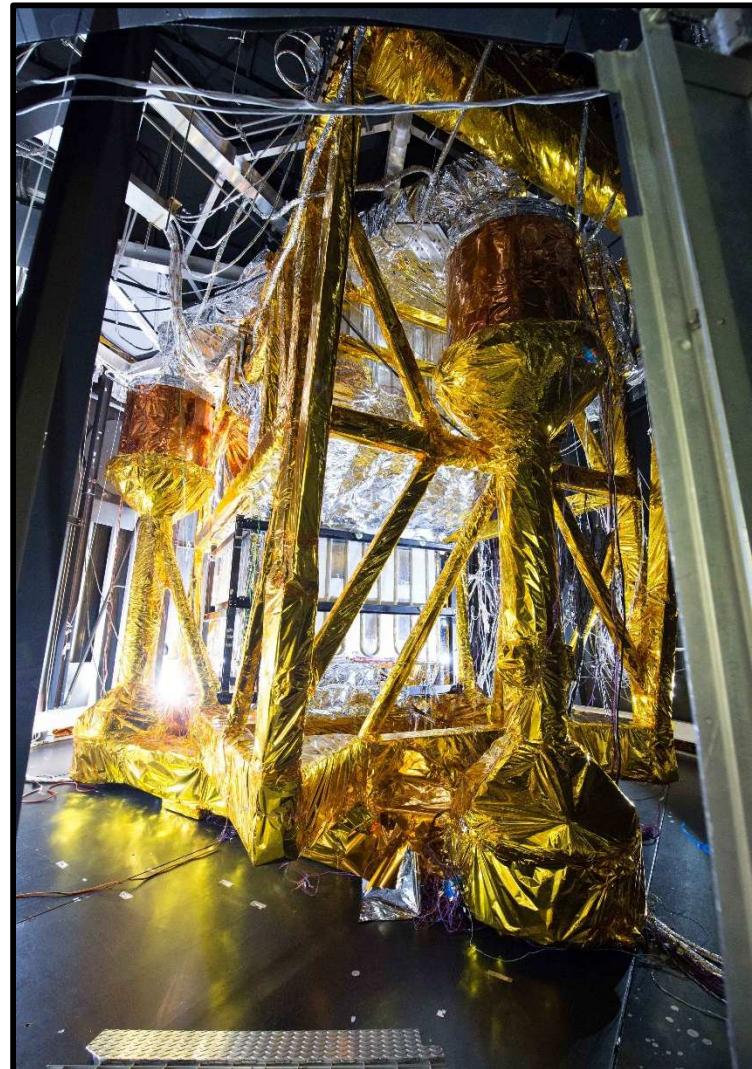
ISIM Test Set-Up



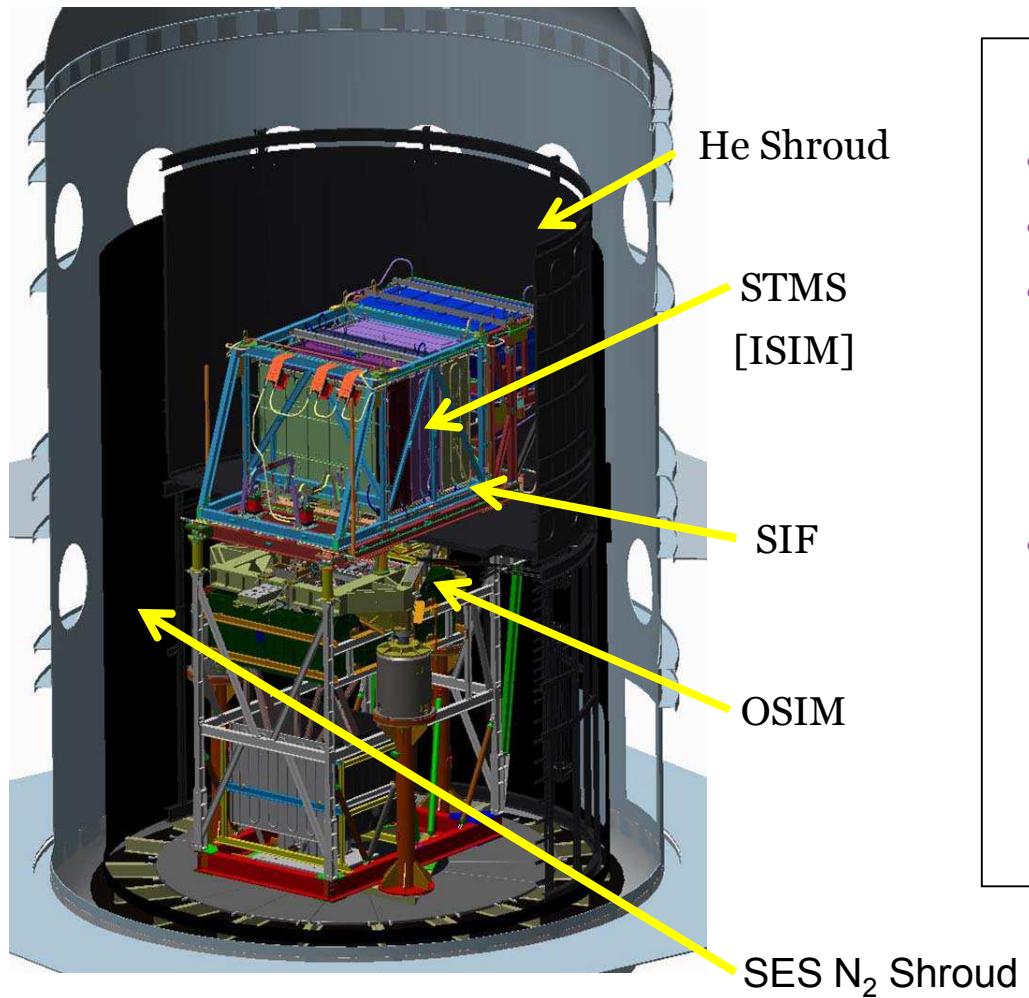
ISIM Test Set-Up



ISIM Test Set-Up



Facility Requirements for ISIM CV3



Thermal Zones

- SES Shroud ($\text{LN}_2 \rightarrow \text{GN}_2$)
 - Helium Shroud (5 GHe ckts)
 - 41 Cryopanels
 - 4 TCUs
 - 6 LN_2 -only lines
 - 5 GHe circuits
 - 171 Heater circuits
 - 9 Heater Racks
 - 15 LS-336s
- 10 helium zones are cooled using a 1.0 kW helium refrigeration system



ISIM Test Summary CV1 – CV3

Item	CV1	CV2	CV3
Pump-down Date	8/29/2013	6/17/2014	10/27/2016
He skid Shutdowns	6	3	1
Power outages	1	3	0
Total days of testing	73	116	109
Total consumables	LN ₂ (gallons)	520K	1.03M
	Helium	20 bottles	20 bottles



Instrumentation Reliability

Instrumentation included >1000 temperature sensors total for all three CV tests

Temp Sensors	CV1	CV2	CV3
T Thermocouples	366	396	375
Silicon Diodes	242	246	248
Platinum Resistance Thermometers (PRTs)	242	248	248
Cernox sensors	80	80	108
Heater control sensors	191	193	193
Total:	1121	1163	1172
% Failure:	4.6	3.2	1.9

Total failure rate for monitoring sensors improvement ~1.3% each test



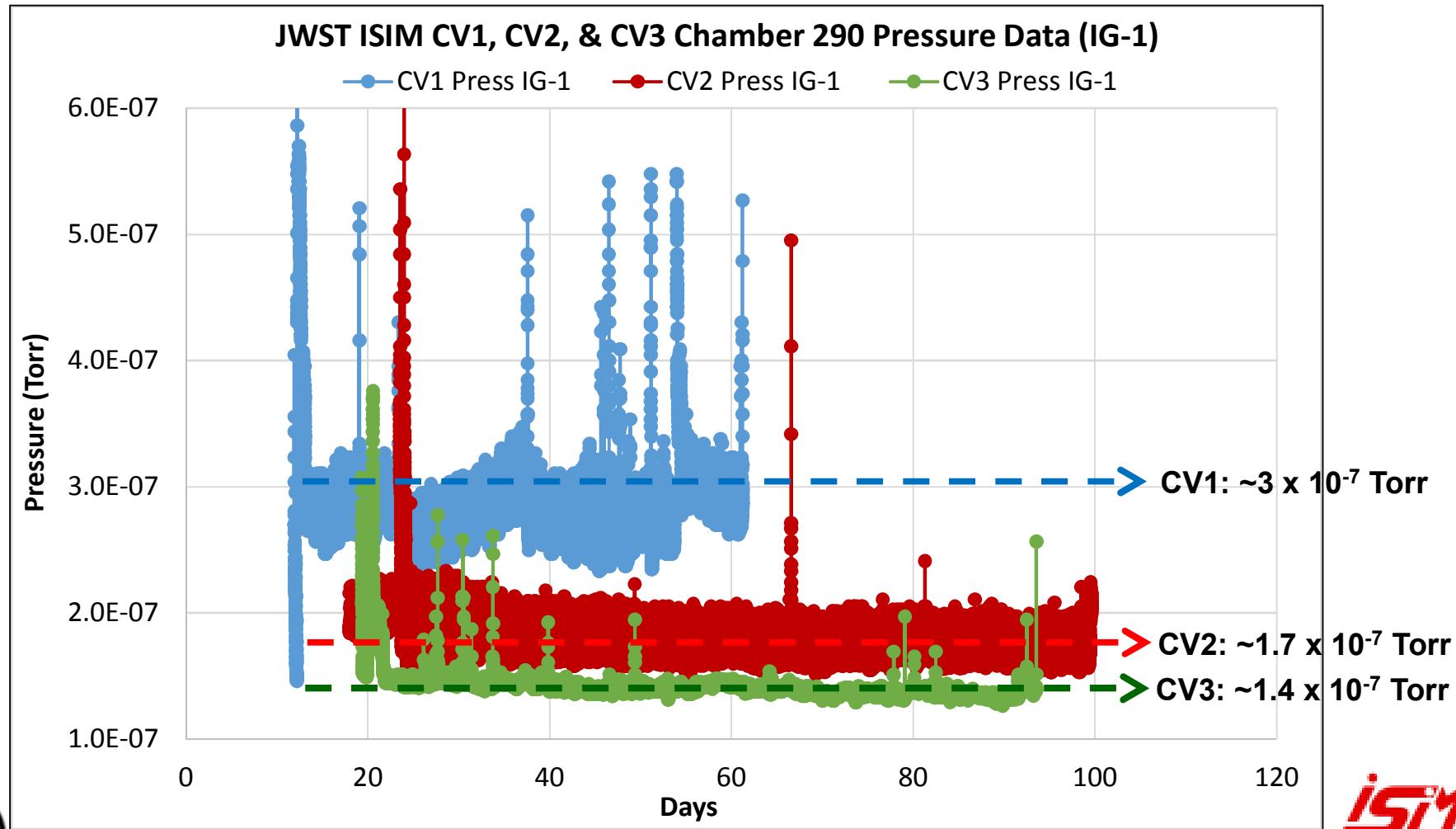
Chamber Vacuum Performance: Pumpdown CVs

Pressure (Torr)	Time from start CV1	Time from start CV2	Time from start CV3
5.0×10^{-5}	29 hrs (1.2 days)	7.8 hrs (0.33 days)	3.5 hrs (0.15 days)
1.0×10^{-5}	35 hrs (1.5 days)	20.6 hrs (0.86 days)	11.1 hrs (0.46 days)
5.0×10^{-6}	46 hrs (1.9 days)	27 hrs (1.13 days)	24.5 hrs (1.02 days)
1.0×10^{-6}	108 hrs (4.5 days)	101 hrs (4.2 days)	88.2 hrs (3.7 days)
5.0×10^{-7}	128 hrs (5.3 days)	160 hrs (6.7 days)	177.6 hrs (7.4 days)



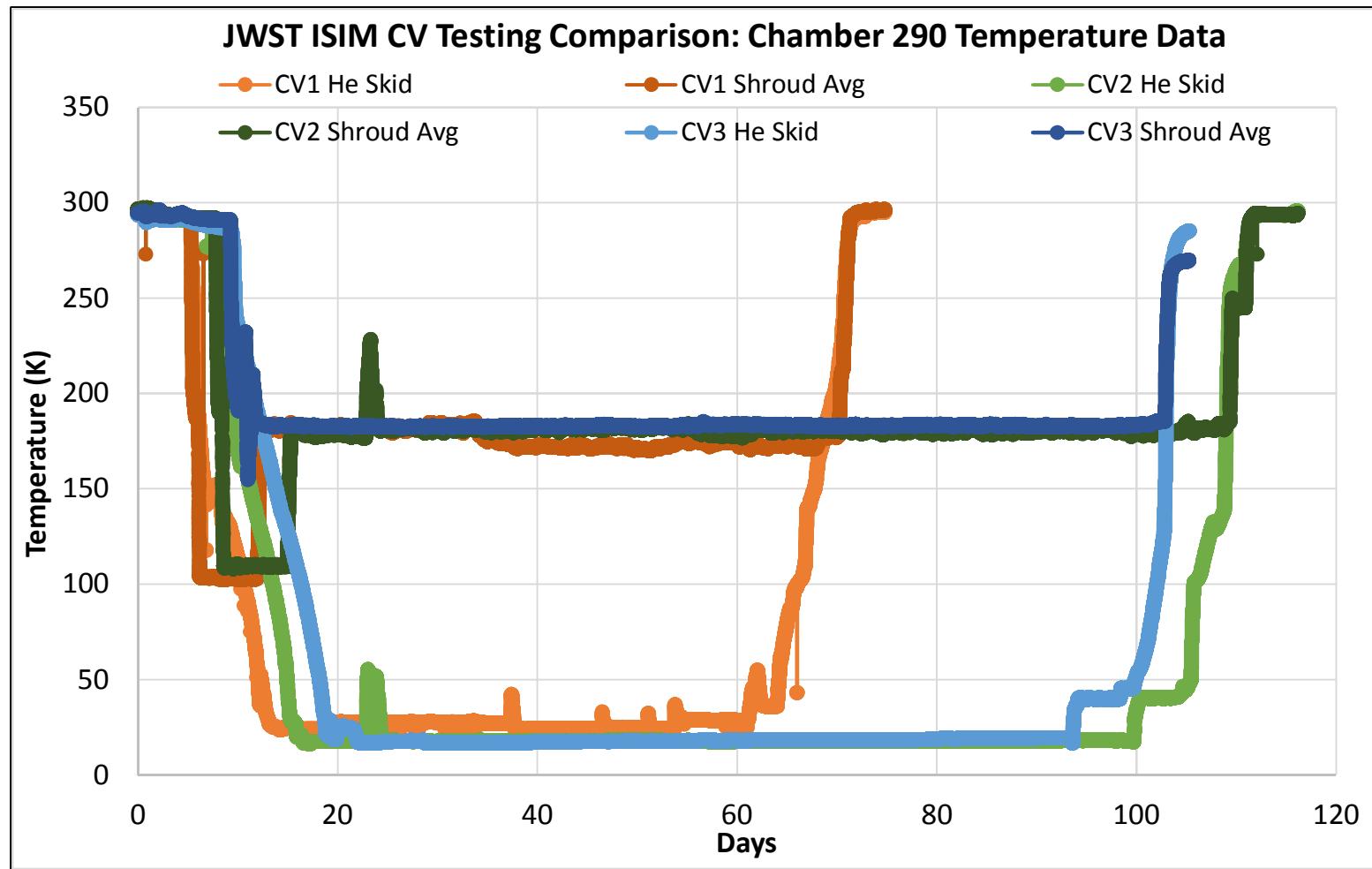
Chamber Vacuum Performance: CV1 vs. CV2 vs. CV3

During steady-state (cool-down & warm-up omitted), vacuum pressure improved with each CV test



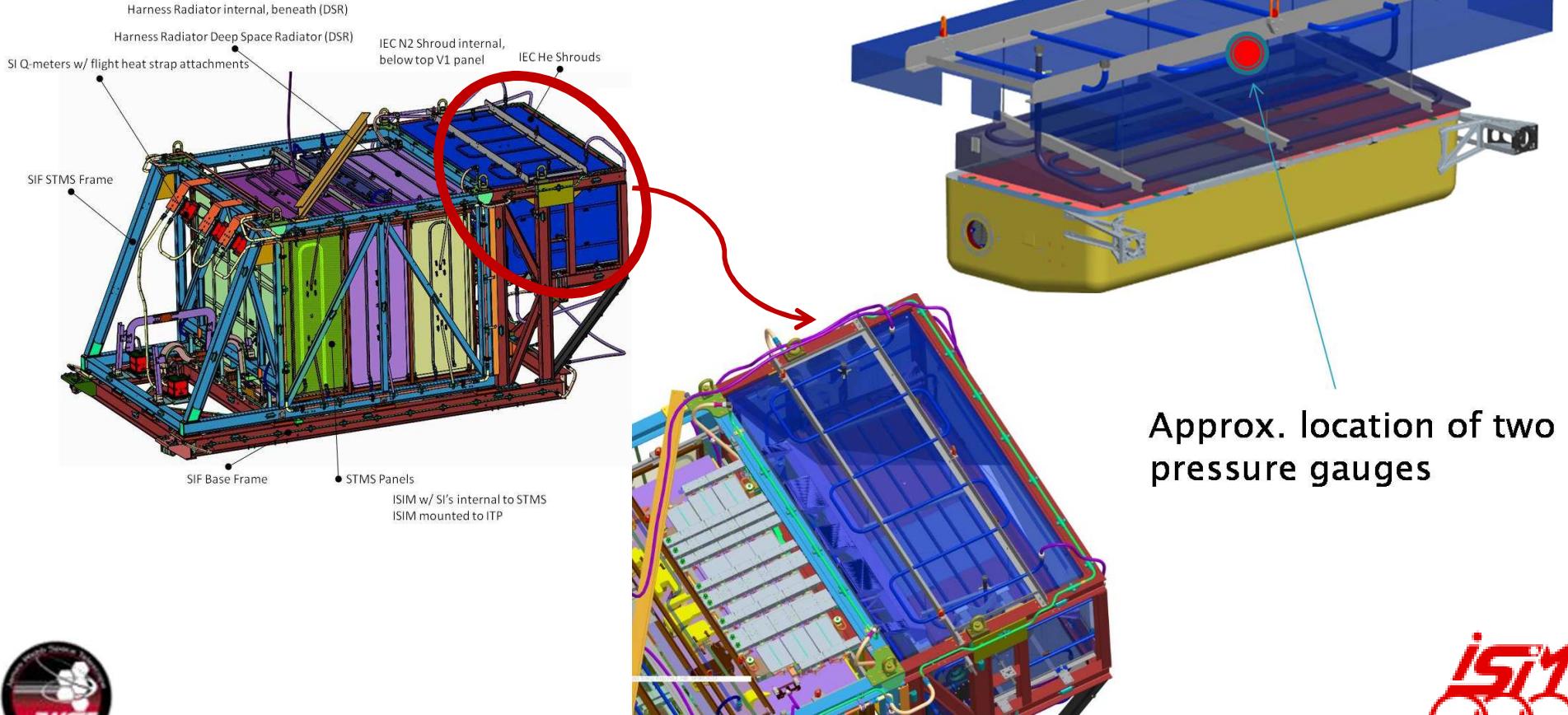
Shrouds Temp Performance CV1 vs. CV2 vs. CV3

At steady state: Helium shroud average achieved: $18K \pm 1K$ || LN_2 shroud average: $180K \pm 3K$



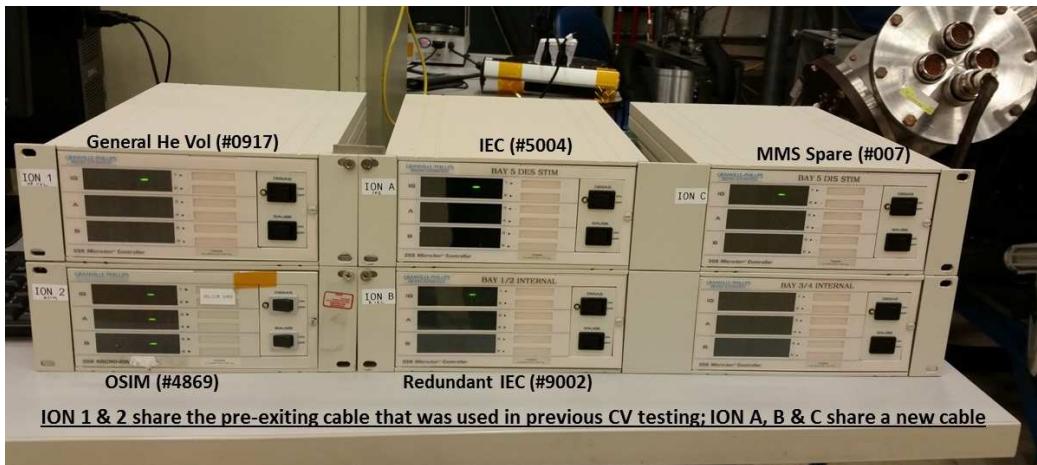
Notable Facility Improvements CV1 → CV2 → CV3

- Micro Ion Gauges (IGs) for the ISIM Electronics Compartment (IEC)
 - CV2: moved one to IEC shroud volume
 - CV3: added redundant IEC shroud volume micro IG

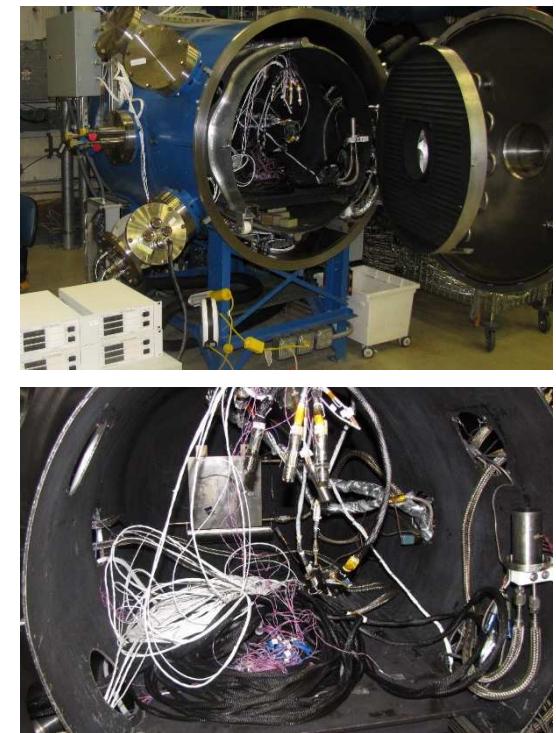


Notable Facility Improvements CV1 → CV2 → CV3

- Redundant micro ion gauge for IEC
- During check-out of the CV2 IGs, it was discovered that the extension used for the IEC IG was the root cause for the erratic and unreliable readings (per the spec sheet, maximum cable length allowable is 50')
- Cross-calibration of existing and new harnesses (+1 new redundant IEC micro IG) was performed in Facility 281

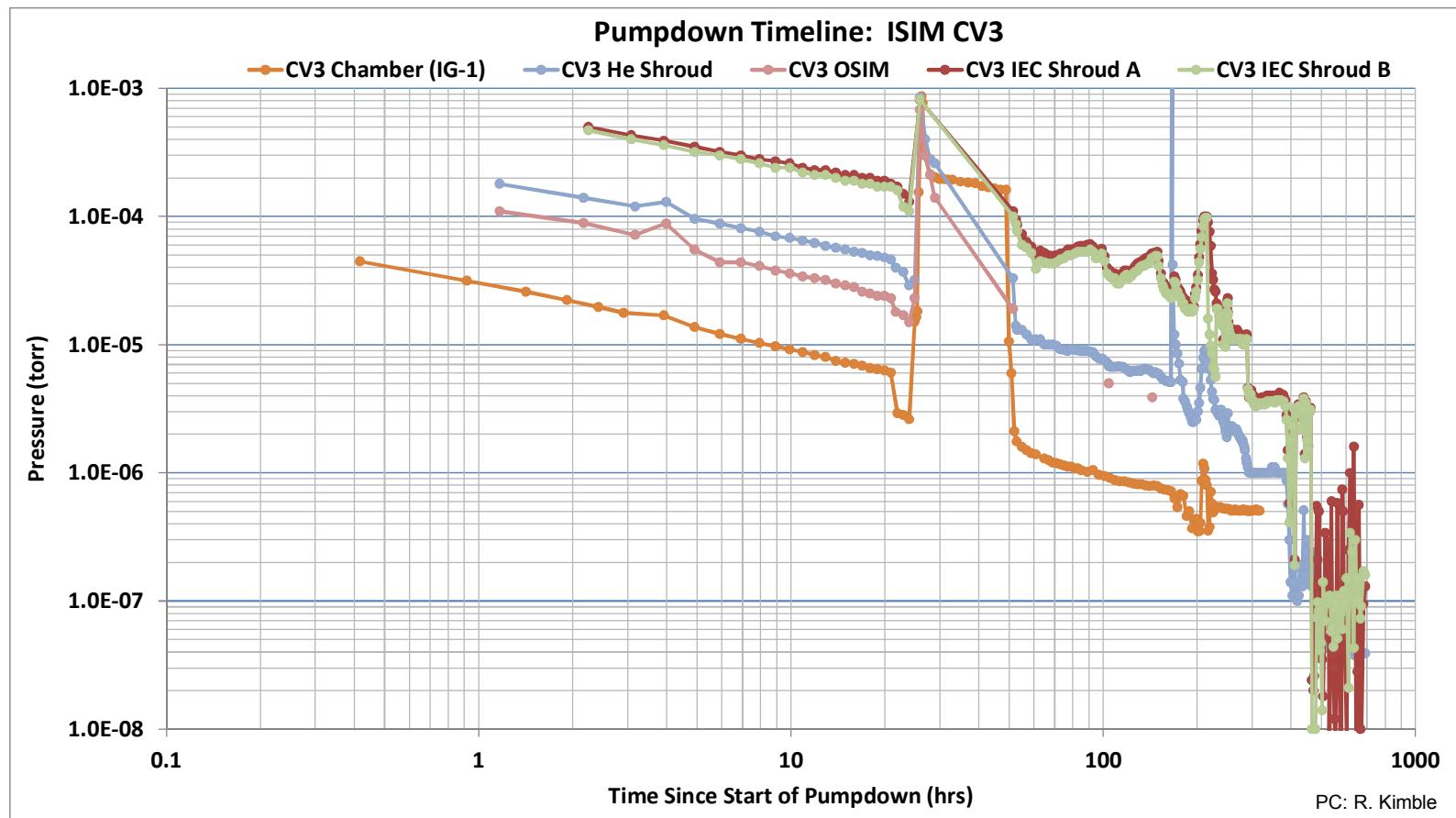


ION 1 & 2 share the pre-existing cable that was used in previous CV testing; ION A, B & C share a new cable



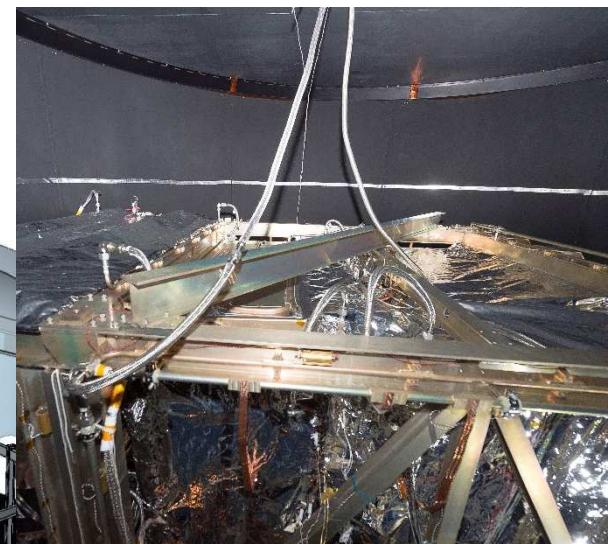
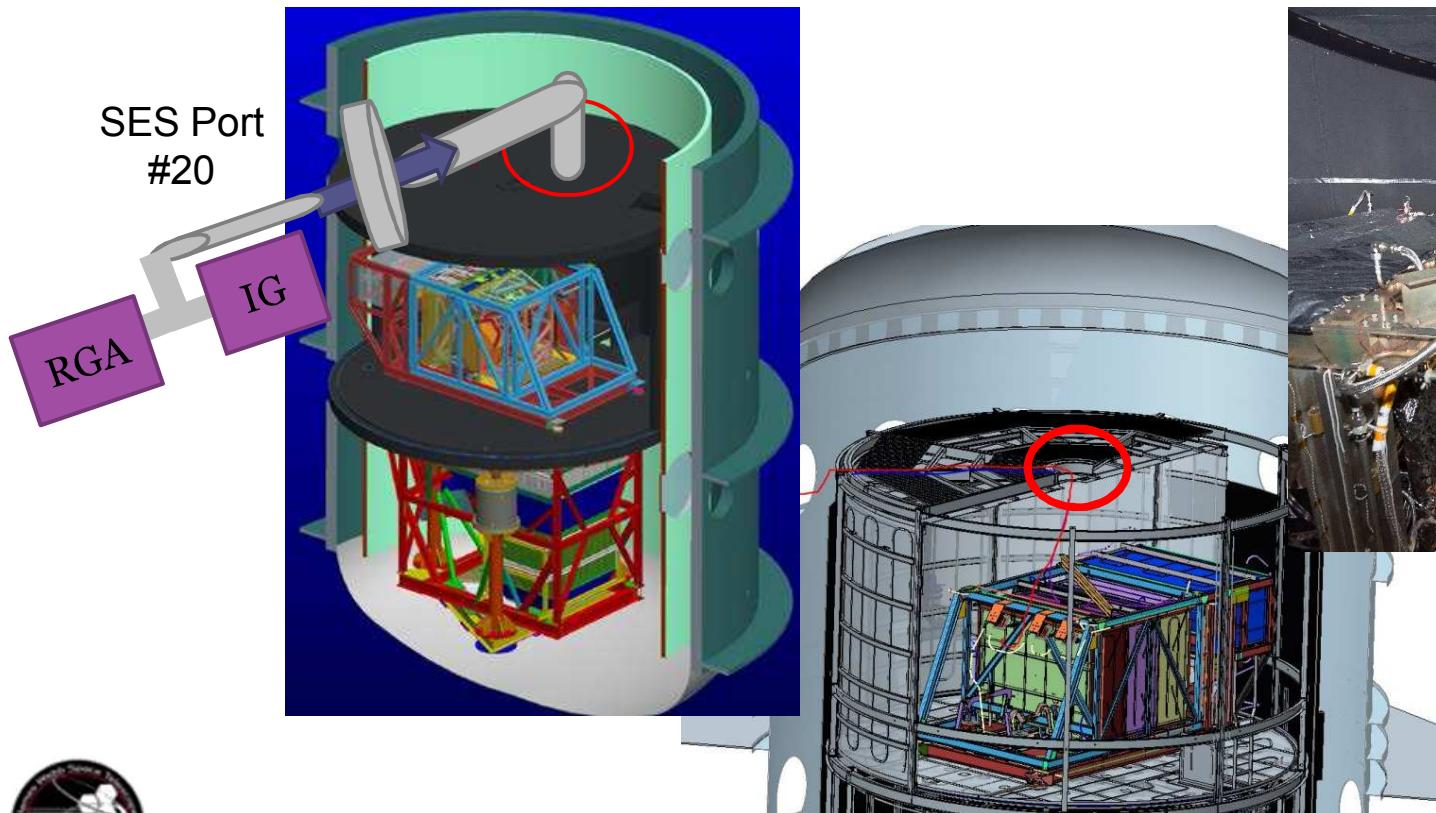
Notable Facility Improvements CV1 → CV2 → CV3

- Redundant micro ion gauge for IEC



Notable Facility Improvements CV1 → CV2 → CV3

- Residual Gas Analyzer (RGA) to monitor STMS inside helium shroud
 - CV2: Added a RGA using flex lines into helium volume
 - CV3: Bought new calibrated RGA; used SS tubing instead of flex lines



Notable Facility Improvements CV1 → CV2 → CV3

Two objectives of the RGA efforts

1. Measure helium test parasitic heat load on the MIRI Cooler
2. Verify MIRI cooler helium leak rate post-vibe to meet end-of-life (10.85) requirement not to exceed 1%

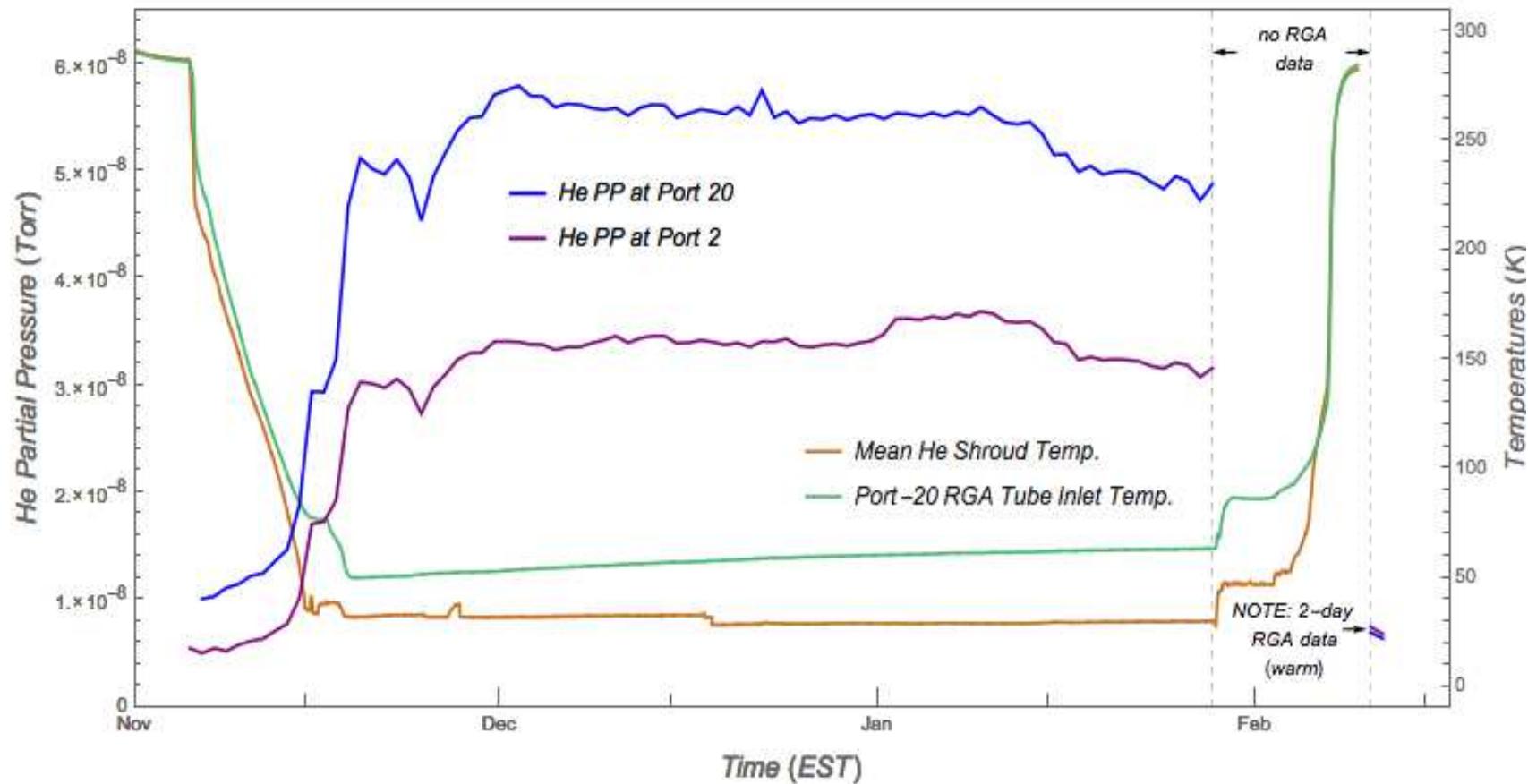


- Verified the heat load on the MIRI Cooler – less than 0.7 mW: Good!
- Helium background in chamber too high to verify cooler leak rate



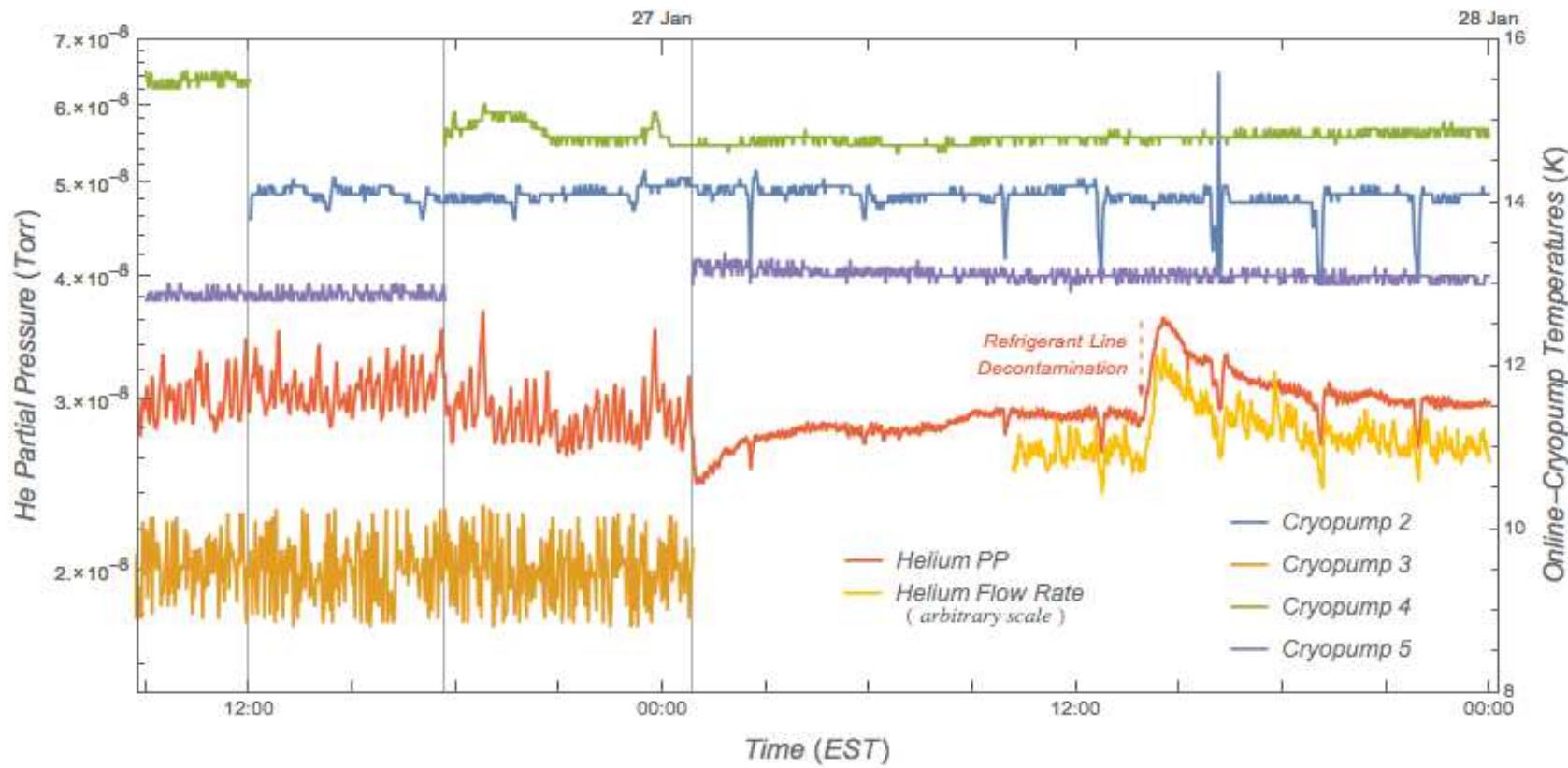
Notable Facility Improvements CV1 → CV2 → CV3

Average Daily Helium Background in CV3



Notable Facility Improvements CV1 → CV2 → CV3

Chamber cryo-pump temperatures & helium partial pressures show a correlation that affects background helium levels within the chamber



Lessons Learned for JWST ISIM CV Testing

#	Lesson Learned	Recommended Actions
1	Project personnel touching and/or changing facility configuration (esp. in between tests) must be verified / communicated	<ul style="list-style-type: none">• Test engineer verifies with project before start of test whether the project made any facility changes• Test engineer requests that the project informs facility team when items are changed, esp. feedthrough plates and during chamber breaks
2	Stringent leak checking is possible and effective	<ul style="list-style-type: none">• Continue adopting the more stringent leak checking techniques to meet high leak-tight requirements• Standard leak check levels were made more stringent for CV2, requiring that measured leaks did not exceed 10⁻⁹ Torr range
3	Helium leak rate detection is a difficult endeavor for high sensitivity measurement requirements	<ul style="list-style-type: none">• Determine the helium background requirement beforehand to gauge whether or not it would be achievable in test• Characterize helium background levels and leak tightness of facility prior to executing leak rate measurements
4	Do not assume reliability of the SES LN ₂ skid, or any test-critical facility system from one test after another	<ul style="list-style-type: none">• Check programmable logic control (PLCs) before major tests• Consider adopting standard operations to include a check-out of major facility systems (i.e. perform a dry-run)



Questions?



Summary of Helium Skid Shutdowns

- Cause #1: low turbine bearing gas temperature alarm
- Cause #2: compressor oil level/temp alarm
- Cause #3: human error
- Cause #4: differential pressure across purifier increased rapidly

CV Test #	Shutdown #	Date	Cause	Pressure Spike	Duration*	He Temp Spike	Duration**
1	1	09/10/13	#1	4.1×10^{-6} Torr	4.0 hrs	52K (+16K)	11.2 hrs
	2	10/05/13	#1	2.8×10^{-4} Torr	5.3 hrs	42K (+15K)	8.5 hrs
	3	10/15/13	#2	1.1×10^{-4} Torr	1.1 hrs	33K (+9K)	14.0 hrs
	4	10/19/13	#2	9.3×10^{-5} Torr	1.1 hrs	32K (+8K)	6.5 hrs
	5	10/22/13	#2	9.2×10^{-5} Torr	6.1 hrs	37K (+13K)	N/A
	6	11/05/13	#2	6.8×10^{-6} Torr	2.1 hrs	N/A (warm-up)	N/A (warm-up)
2	1	06/24/14	#2	3.0×10^{-6} Torr	N/A	199 (<1K)	<15 min
	2	06/26/14	#2	2.8×10^{-6} Torr	N/A	166 (<1K)	<15 min
	3	10/01/14	#3	2.0×10^{-6} Torr	~1 hr	N/A (warm-up)	N/A (warm-up)
3	1	11/7/15	#4	N/A (during pumpdown)	N/A	<0.5K	N/A

*Duration for pressure to return to 10^{-7} Torr

**Duration for helium shroud average temperature to return to temp before shut-down



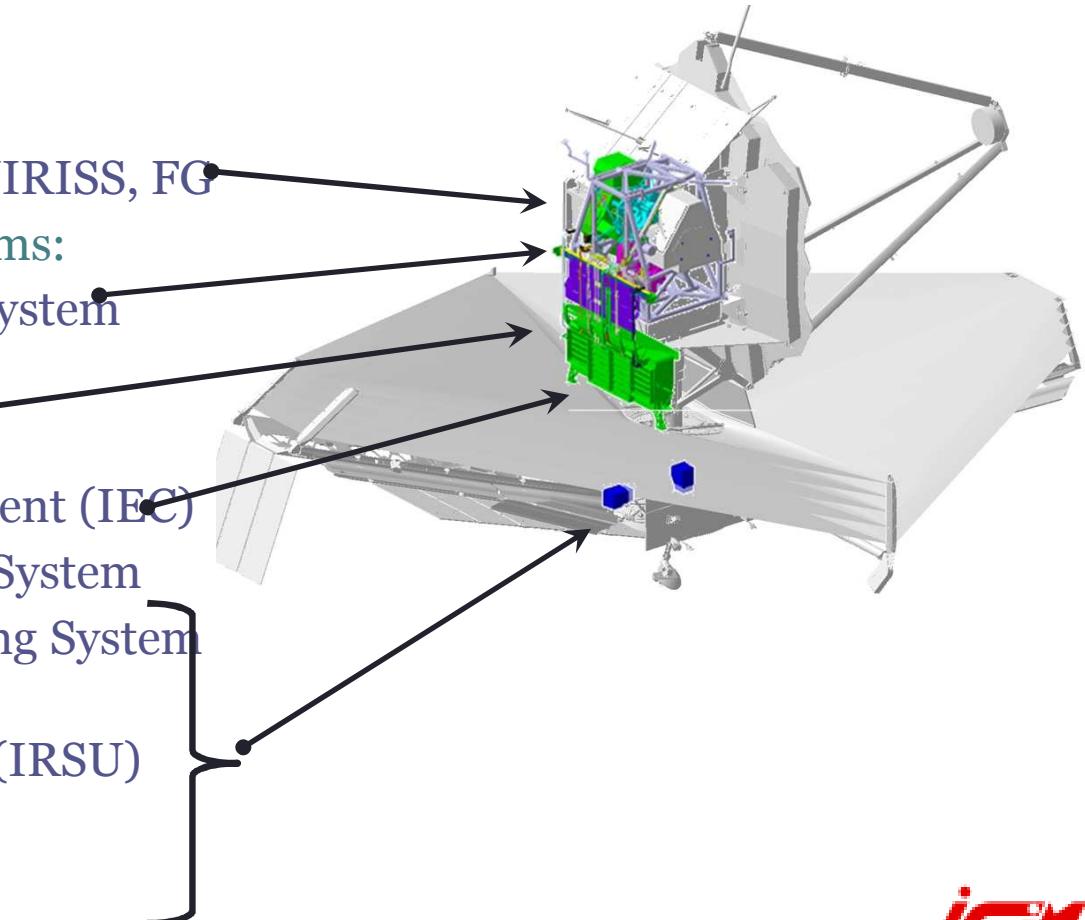
Integrated Science Instrument Module

ISIM is one of three elements that together make up the JWST space vehicle

- Approximately 1.4 metric tons, ~20% of JWST by mass

- The ISIM system consists of:

- Five sensor systems
 - MIRI, NIRCam, NIRSpec, NIRISS, FG
- Nine instrument support systems:
 - Optical metering structure system
 - Electrical Harness System
 - Harness Radiator System
 - ISIM Electronics Compartment (IEC)
 - Cryogenic Thermal Control System
 - Command and Data Handling System (ICDH)
 - ISIM Remote Services Unit (IRSU)
 - Flight Software System
 - Operations Scripts System



Actions/Issues after CV3 (before Core 2)

Description	Status/Notes	Target completion
Cryopump #4 needs replacement actuator with a manual override, limit switches	Actuator received.	2/26/2016
Cryopump #1 will not pump down it is believed because the rebuilt seals on the main valve actuator are leaking through to the cryo cavity.	Spare parts received.	3/9/2016
Cryopump #6 main valve will not close because main valve actuator is leaking. Actuator will need to be fixed.	Spare parts received.	3/23/2016
Coldheads on cryopump #7 is banging Intermittently.	Coldheads received.	3/18/2016
Cryopump #2 is still banging intermittently: send back to PHPK for evaluation of the drive head & displacers		3/21/2016
The LN2 thermal system could not flood the bottom shroud during the test. At the conclusion of the test the LN2 skid will need to be checked out to determine why the LN2 pump pressure on both pumps is low. Cavitation do to PLC logic. Pump vent valves do not appear to open to prime the pump during start up	PLC changes	4/11/2016
High Pressure GN2 TESCOM REGULATOR Fabrication and INSTALLATION		3/4/2016
RV replacement for GN2 backfill system		3/11/2016
Cryopump #7: Oil inside cold-heads	PO placed 02/10/16	3/18/2016



Helium Skid Shutdowns

Total of one (1) helium skid shutdown

- In an attempt to expedite cool-down helium skid compressor start-up early
- Over-temp shut-down skid
- During pumpdown on 11/7/2015 0:10; minimal effect on the test

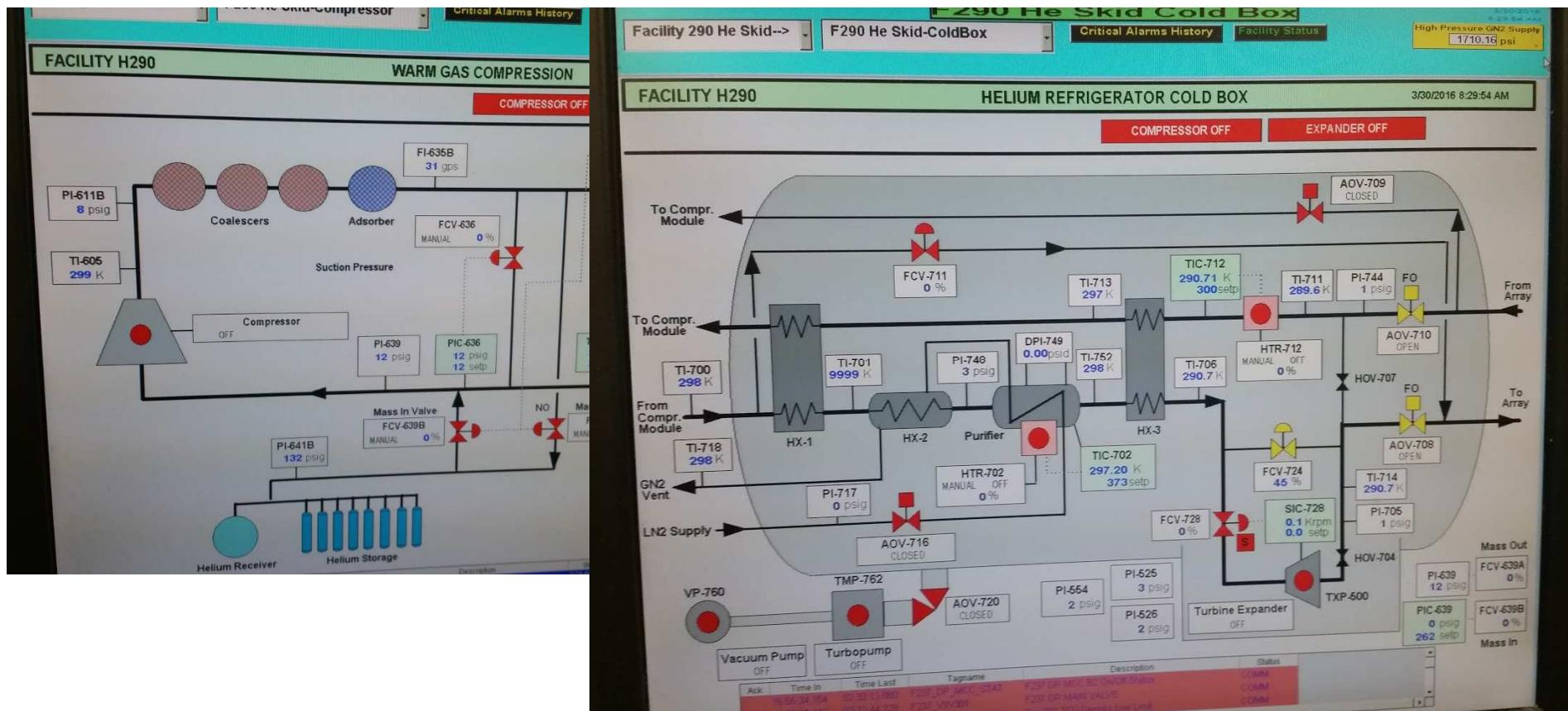
Response to a PR written about this:

Resolution: The helium skid did not lose power as stated in the PR. Instead, (only) the turbine was shut-down as a result the expander wheel hitting a inlet pressure alarm. The cross-over to turbine mode (from bypass mode) was accelerated because the differential pressure across the purifier was going up rabidly. The valve to the turbine was opened when the inlet temperature to the turbine was at 140K, instead of waiting for it to get to 100K. As a result, the higher inlet gas temperature corresponded to an inlet pressure that exceeded the limits of the expander wheel and consequently shut-down the turbine. In response, the turbine throttle valve immediately failed closed to 0%, and the bypass valve opened to almost 50%. The system (valve positioning) was restored to its configuration (prior to the turbine shutdown) well within 15 minutes. The result was a 10K spike in the expander outlet temperature (helium shroud inlet temperature), but the spike was back to its pre-shutdown temperature within 15 minutes. The effect on the helium shroud average temperatures was less than 0.5K.

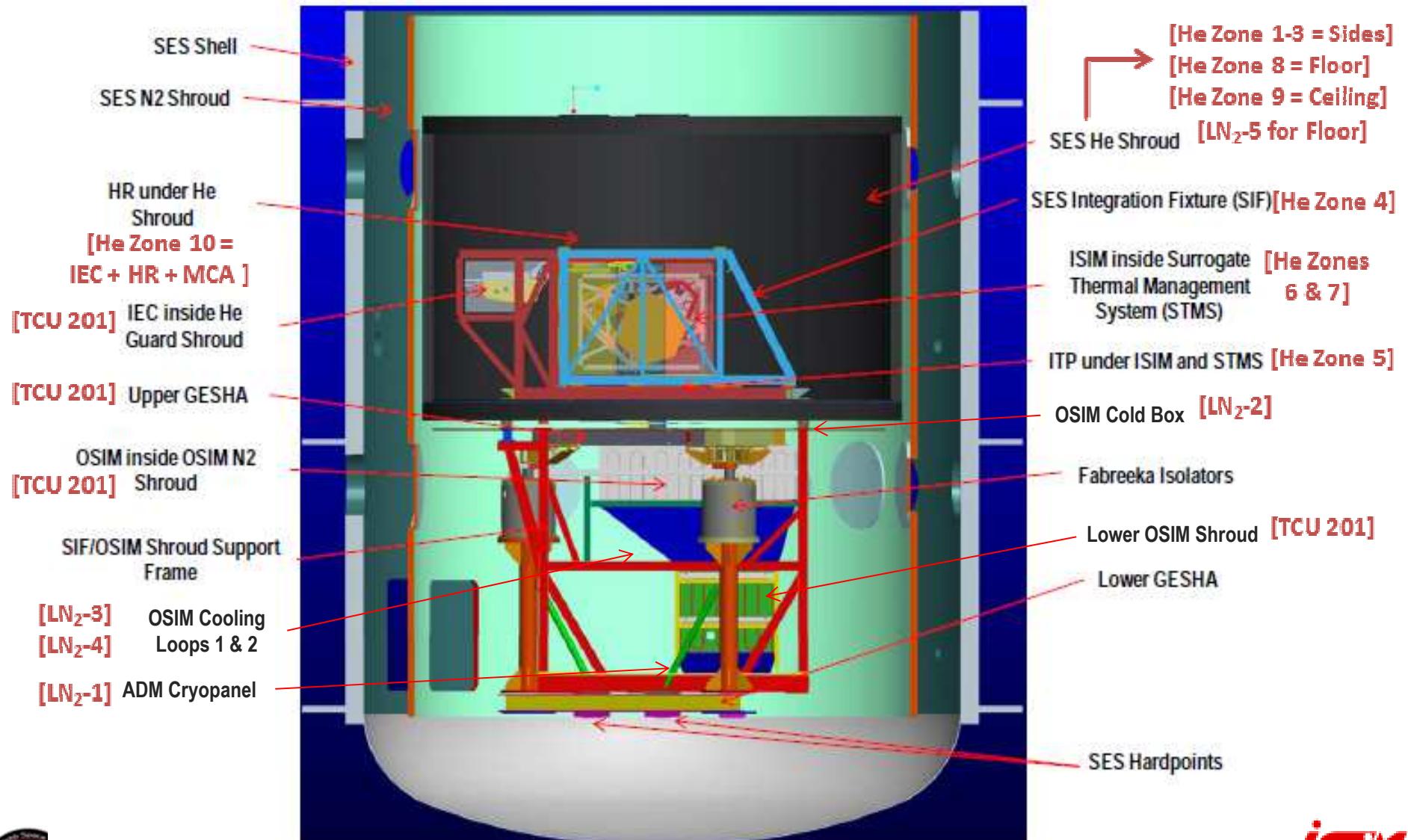


Helium Skid Shutdowns

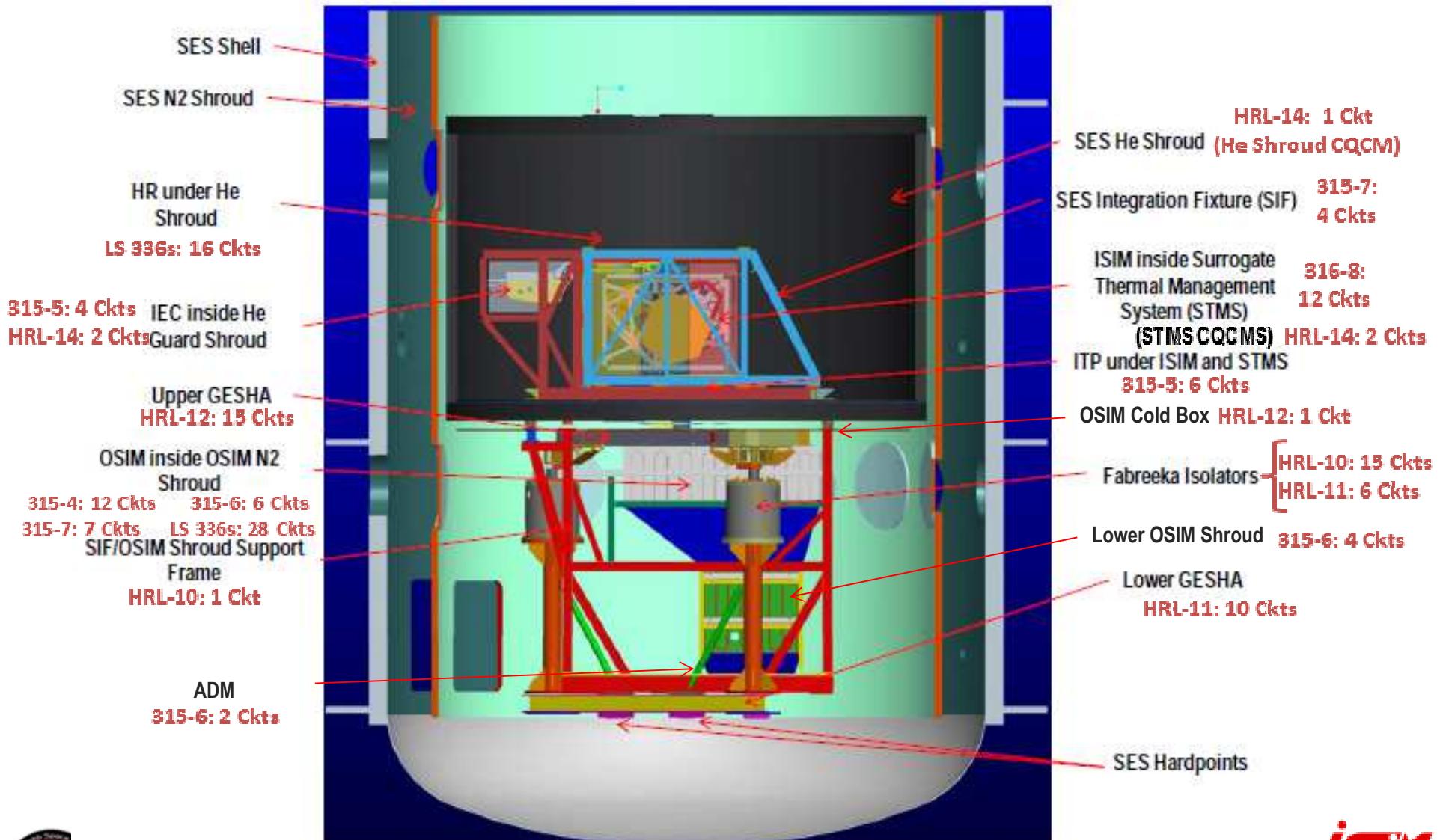
Total of one (1) helium skid shutdown during pumpdown on 11/7/2015 0:10



LN2 & GHe Cryo Zones [TCUs, LN2-only Lines, & He Lines]



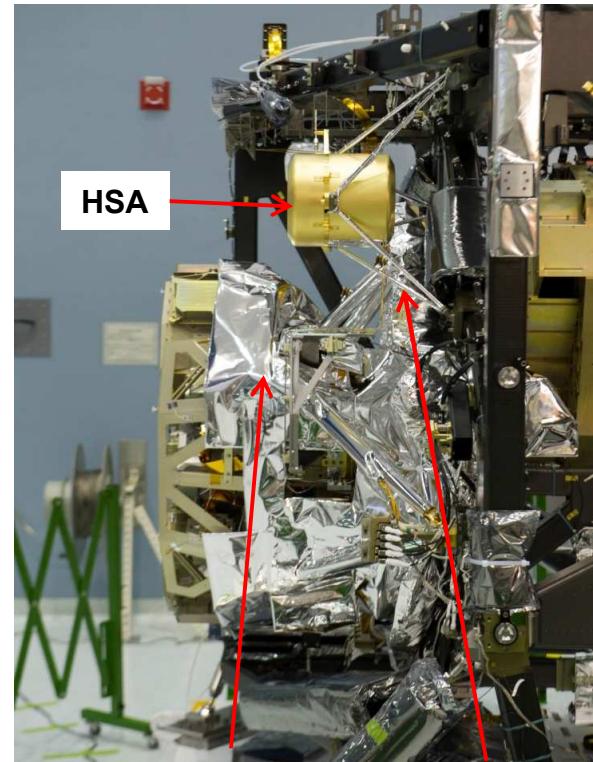
Heater Zones [Heater Racks]



Test Configuration for ISIM CV Testing

Notable hardware changes since CV2:

- NIRCam new detectors arrays
- MIRI cooler flight unit (CV2 had flight-like assemblies: cooler lines and heat exchanger stage assembly, HSA)
- NIRSpec kinematic mounts change
- FGS guider detector assemblies
- New focal plane electronics



Refrigerant Lines and Line Support



Facility Requirements for ISIM CV3

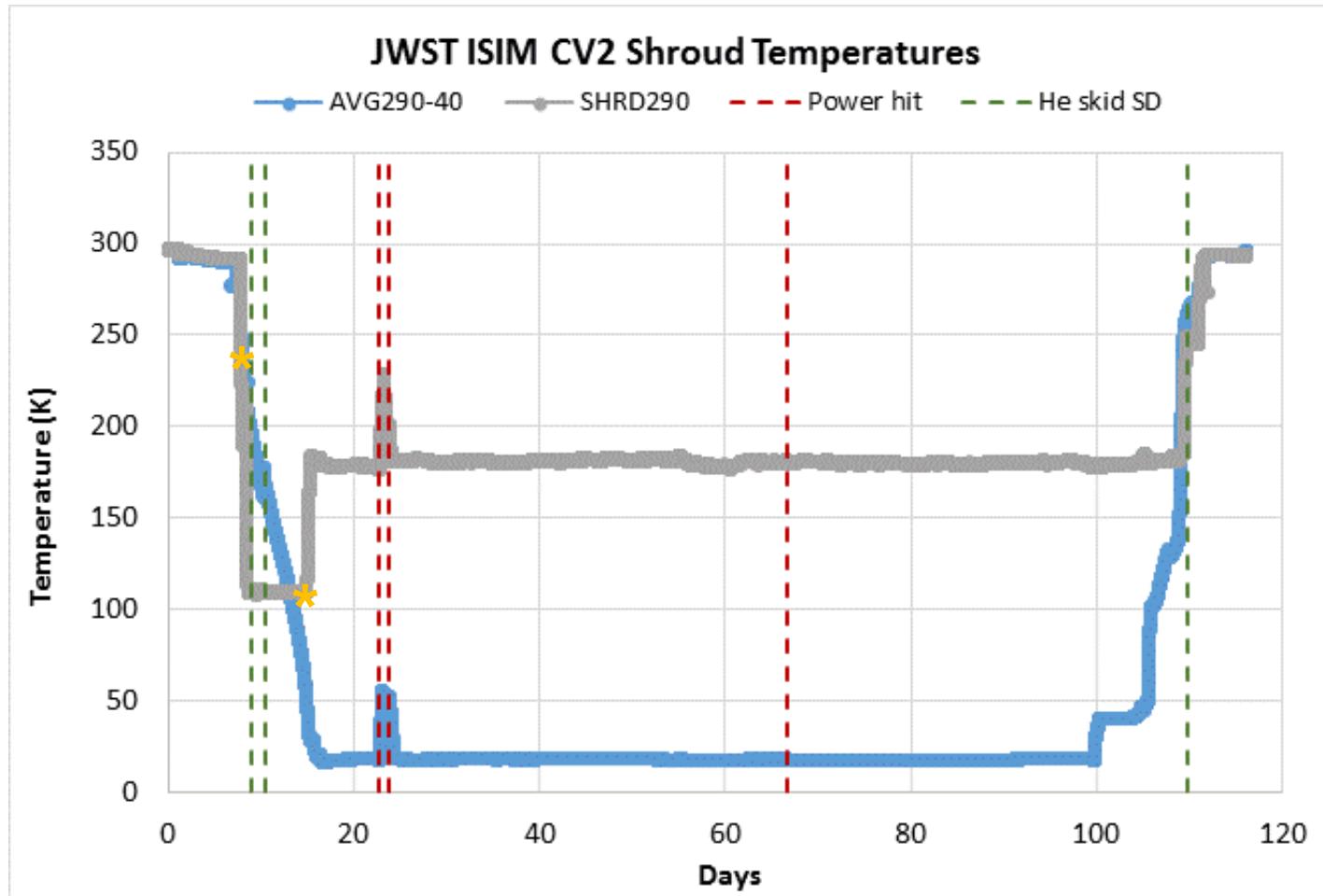
- Thermal Zones
 - SES Shroud ($\text{LN}_2 \rightarrow \text{GN}_2$)
 - Helium Shroud (5 GHe circuits)
 - 41 Cryopanels
 - 4 TCUs
 - 6 LN_2 -only lines
 - 5 GHe circuits (re-routing of some zones from CV1)
 - 171 Heater circuits
 - 9 Heater racks
 - 15 LS-336s
- Instrumentation
 - 979 monitoring sensors
 - 2 new diodes for CV3
 - 28 new Cernox sensors for CV3
 - 375 TCs (20 removed from CV2)
 - 604 other sensors
 - 193 heater control sensors

New in CV3	Description
1239-1240	HR GSE Blankets (diodes)
1357-1376	Flight Heat Straps (Cernox)
1580-1587	MIRI GSE Heat Straps (Cernox)



Shrouds Temperature Performance

At steady state: Helium shroud average achieved: $18K \pm 1K$ || LN₂ shroud average: $180K \pm 3K$



* = Switch GN₂ → LN₂ (DAY 8 – 6/24/14 03:44)
LN₂ → GN₂ (DAY 15 - 6/30/14 22:40)



Notable Facility Changes Since CV2

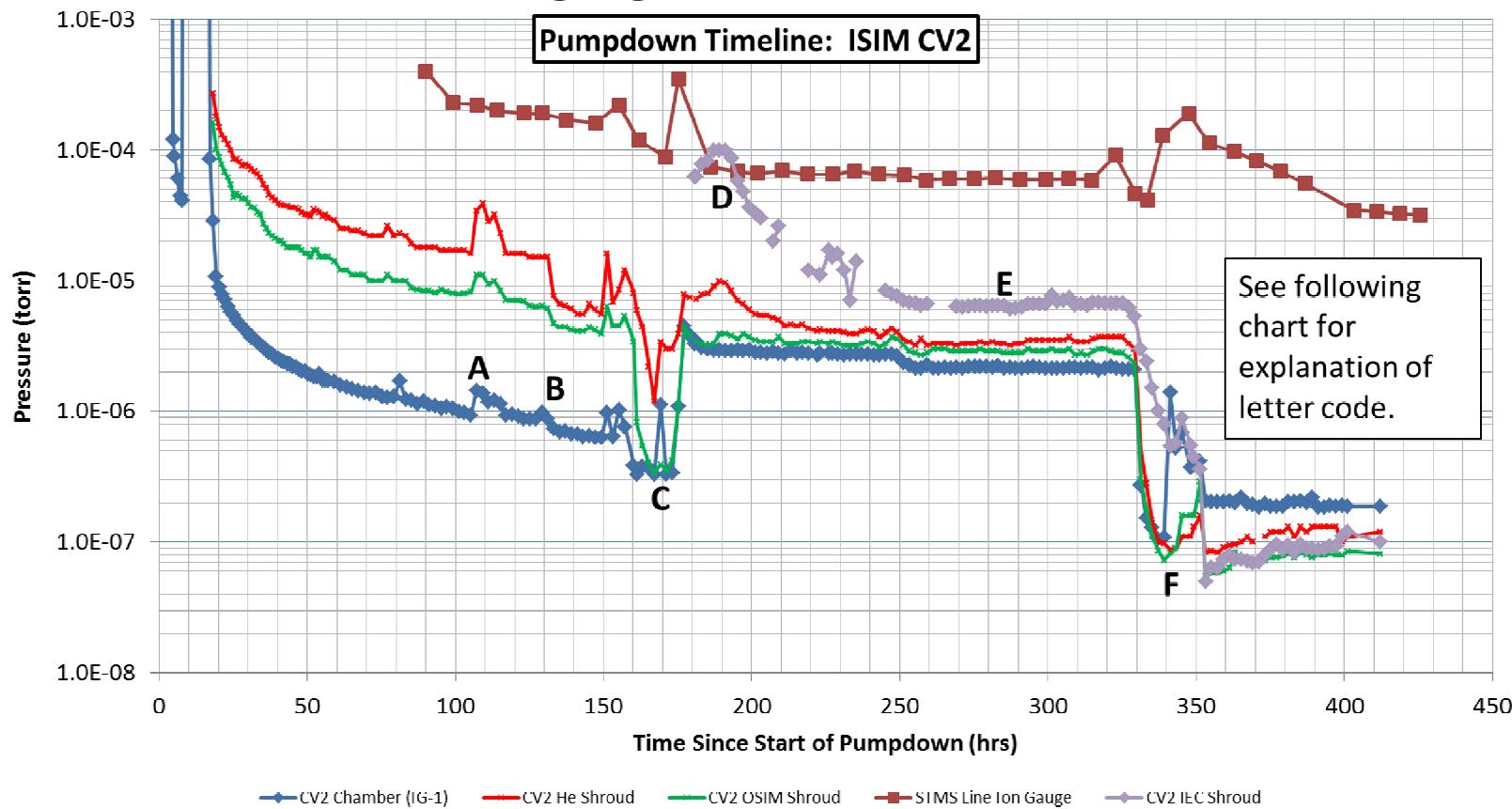
- 1) Redundant micro ion gauge for IEC
- 2) New, calibrated RGA for helium shroud volume
- 3) New cryopumps

PR-	Issue	Updated Status
0391	Micro Ion Gauge #1 (IEC shroud) does not power on and stay on	<ul style="list-style-type: none">• Ion gauge was removed and checked-out• A new, redundant micro IG is being provided for CV3• Delivered two IEC micro IGs to ISIM for installation on 9/14/15



Notable Facility Changes Since CV2

1) Redundant micro ion gauge for IEC

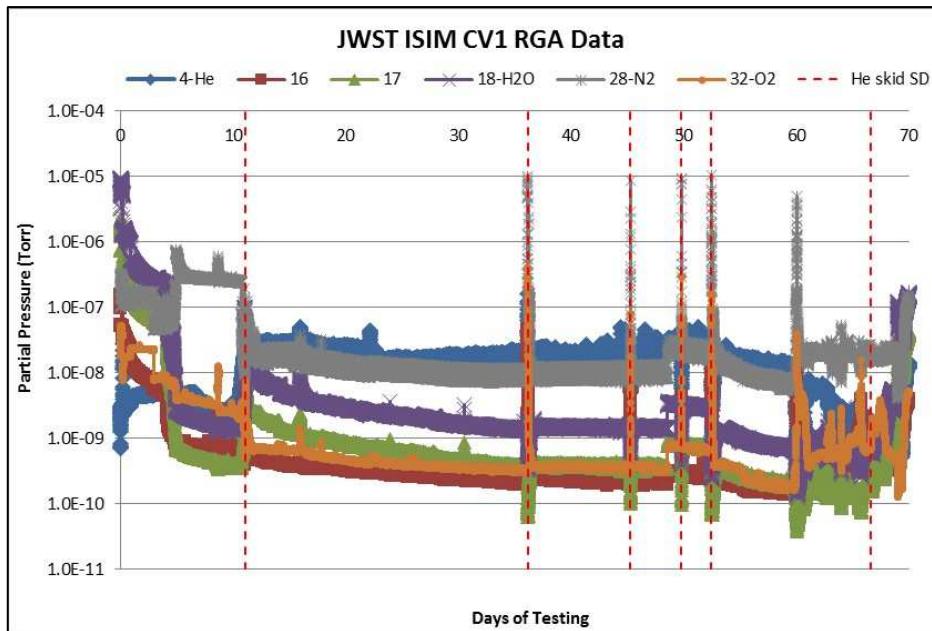


- A: Response to raising IEC N2 panel temp
- B: Response to cooling of CQCM lines
- C: Adjustments to facility N2 shroud
- D: IEC temperature cycle from 273-308 K and back, after which pressure continues to drop as IEC He panels get cold enough to sink water
- E: Pressure in IEC shroud stabilizes, though panels are 130K → 100K, with much lower water vapor pressure than P observed: **suggests an N₂ leak inside IEC shroud; need to check/fix before CV3**
- F: He panels reach temperature for sinking N₂/O₂; pressures everywhere plummet

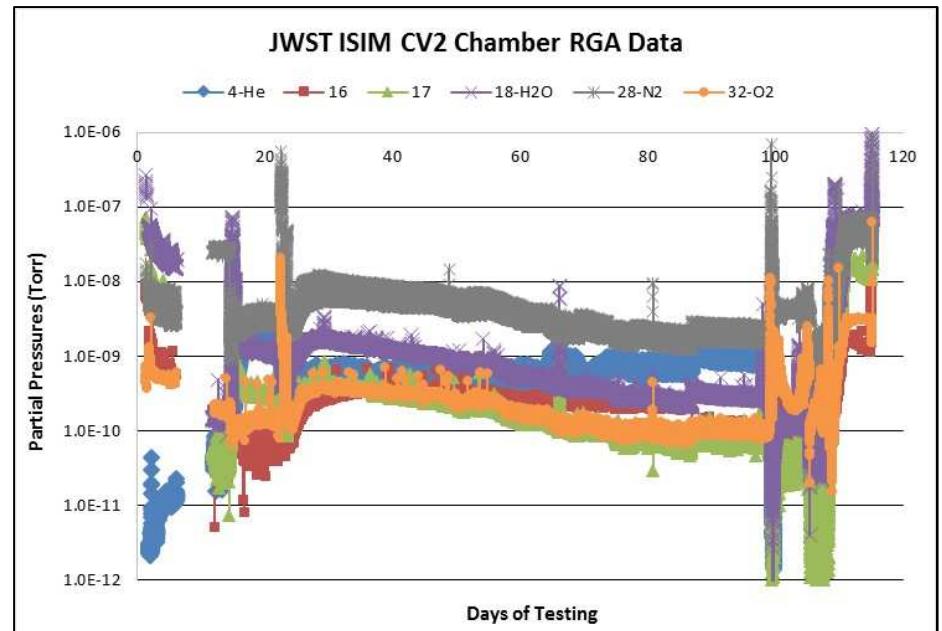


CV1 vs. CV2 Chamber RGA Detection Levels

ISIM CV1: Chamber RGA detected helium levels around 1.5×10^{-7} Torr



ISIM CV2: Chamber RGA detected helium levels around 1.0×10^{-9} Torr



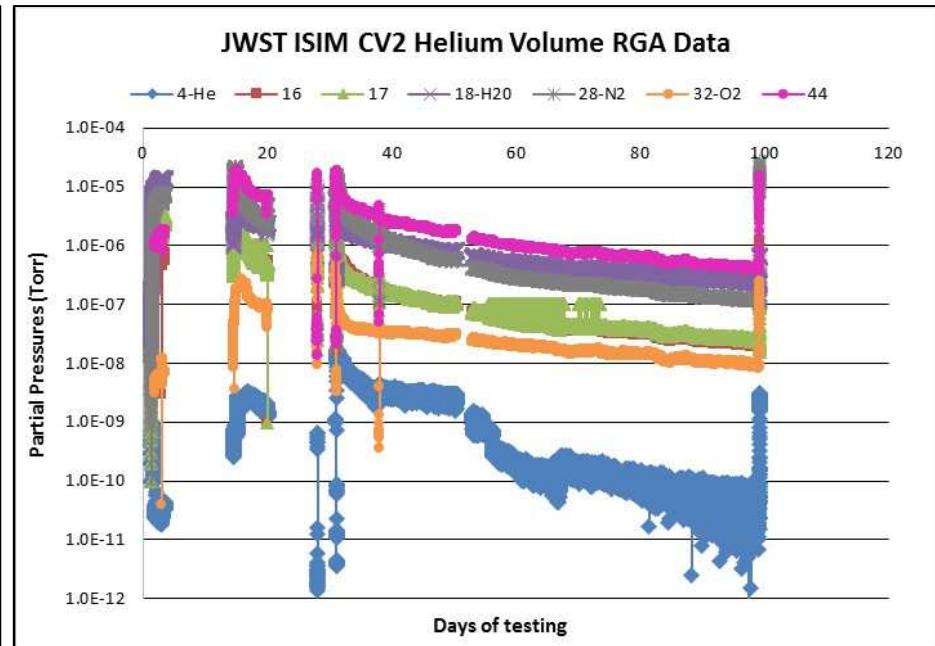
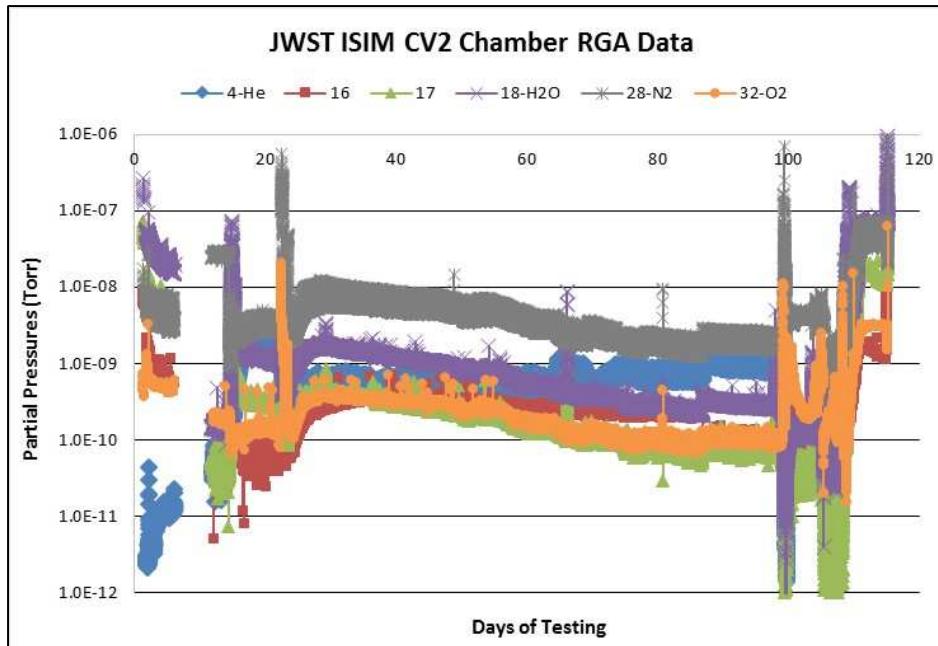
Levels of detected helium using chamber RGA decreased by almost two orders of magnitude from CV1 to CV2



CV2 Chamber RGA vs. Helium Volume RGA Detection

ISIM CV2 Chamber RGA detected helium levels around 1.0×10^{-9} Torr

ISIM CV2 ISIM/STMS volume RGA detected helium levels consistently $<1.0 \times 10^{-8}$ Torr

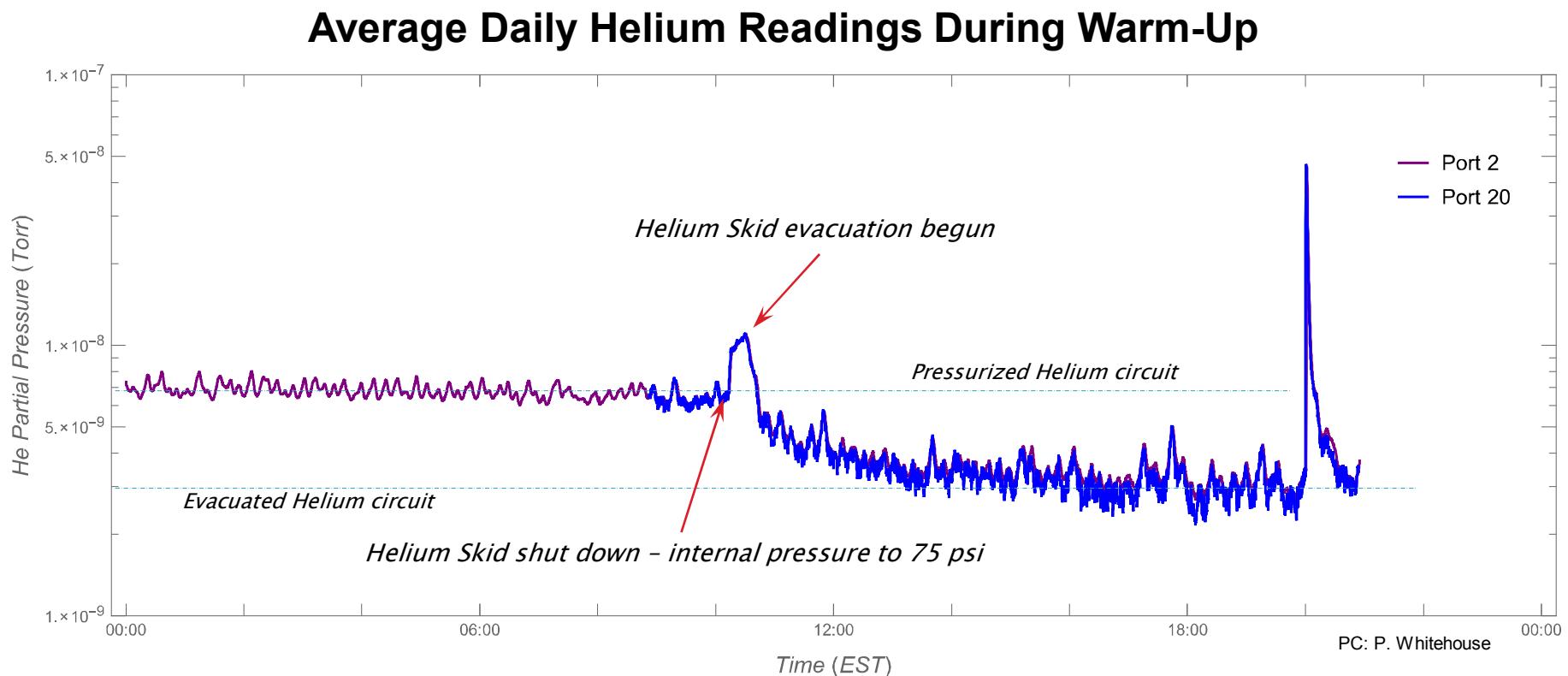


ISIM CV2 Chamber RGA detected helium levels were more consistent throughout the test, whereas the detectable helium levels using the ISIM/STMS RGA slowly decreased throughout the test

Both in CV1 & CV2, the difference between the total chamber RGA partial pressure readings & the chamber IG pressure readings was $\sim 2.0 \times 10^{-7}$ Torr higher pressure (lower vacuum) on the IG



Notable Facility Improvements CV1 → CV2 → CV3



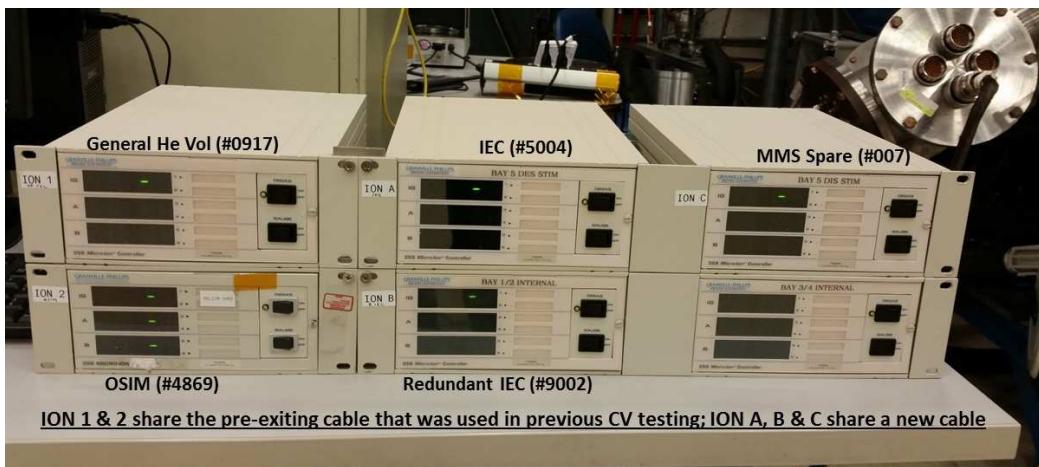
Readings between the two RGAs are consistent at warm temperatures



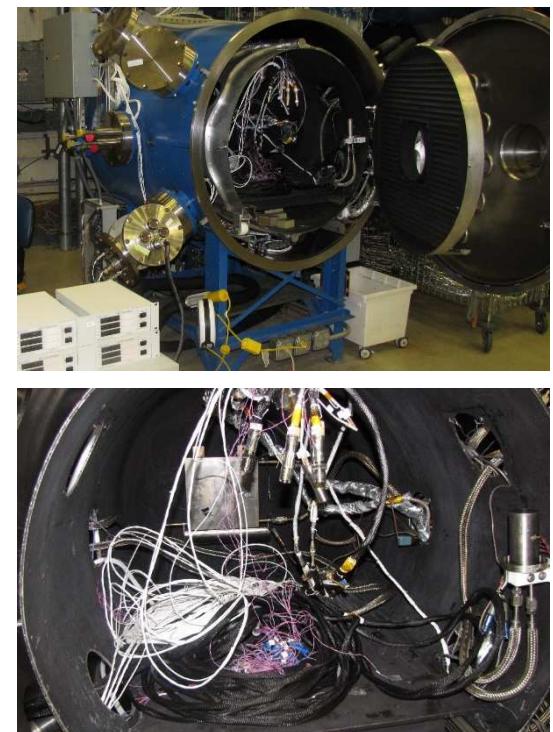
Notable Facility Changes Since CV2

1) Redundant micro ion gauge for IEC

- During check-out of the CV2 IGs, it was discovered that the extension used for the IEC IG was the root cause for the erratic and unreliable readings (per the spec sheet, maximum cable length allowable is 50')
- Cross-calibration of existing and new harnesses (+1 new redundant IEC micro IG) was performed in Facility 281

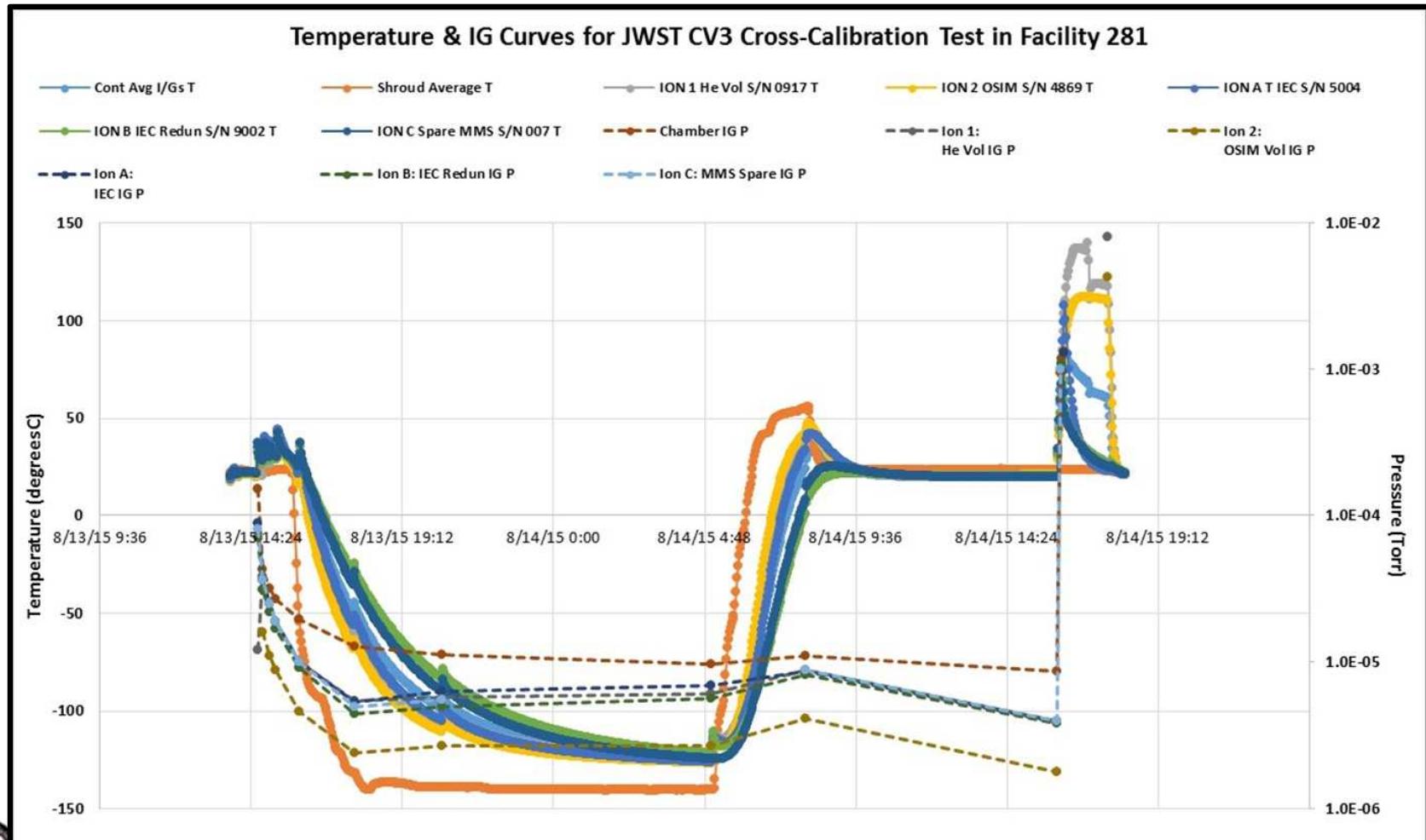


ION 1 & 2 share the pre-existing cable that was used in previous CV testing; ION A, B & C share a new cable



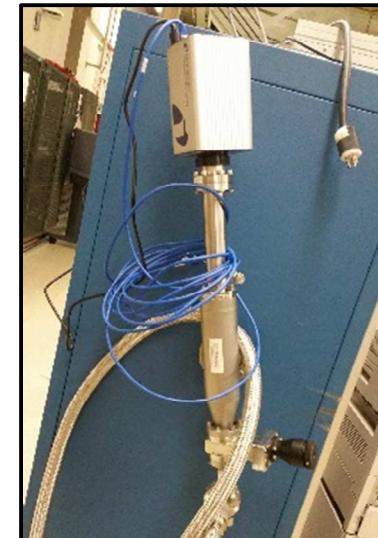
Notable Facility Changes Since CV2

1) Redundant micro ion gauge for IEC



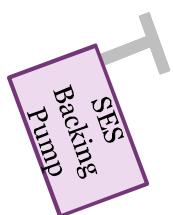
Notable Facility Changes Since CV2

- 1) Redundant micro ion gauge for IEC
 - 2) New, calibrated RGA for helium shroud volume
 - 3) New cryopumps
-
- MIRI requirement: 6.2 K (-266.8°C) at the instrument
 - 2-stage cooler system
 - Accurate heat map required during environmental testing
 - Issues during CV1 & CV2
 - Measured heat loads to cooler from MIRI higher than expected
 - Presumed cause is higher levels of helium in chamber

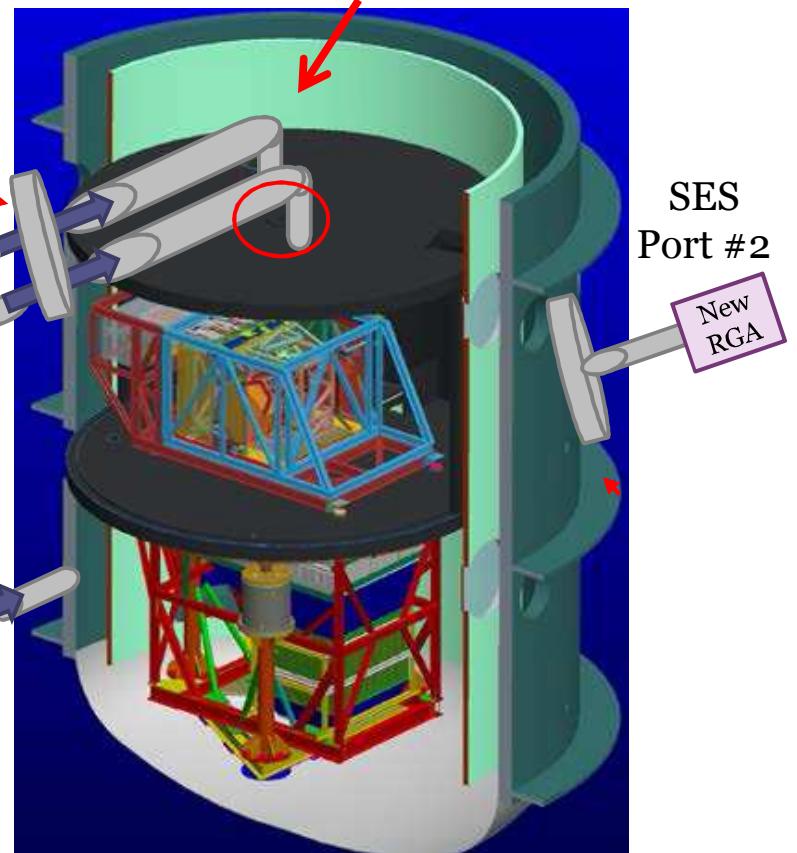
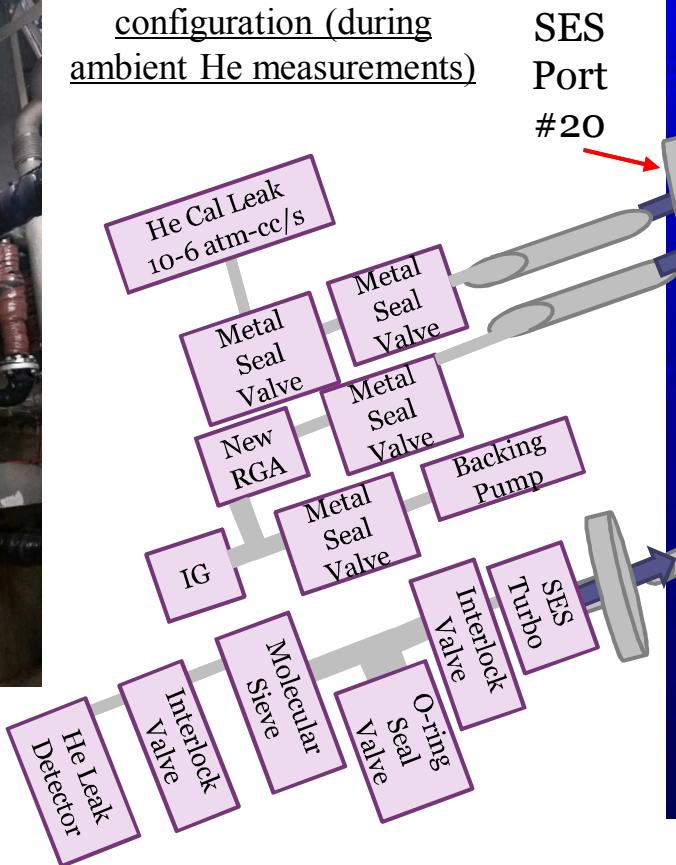


Notable Facility Changes Since CV2

2) New, calibrated RGA for helium shroud volume



Most sensitive configuration (during ambient He measurements)

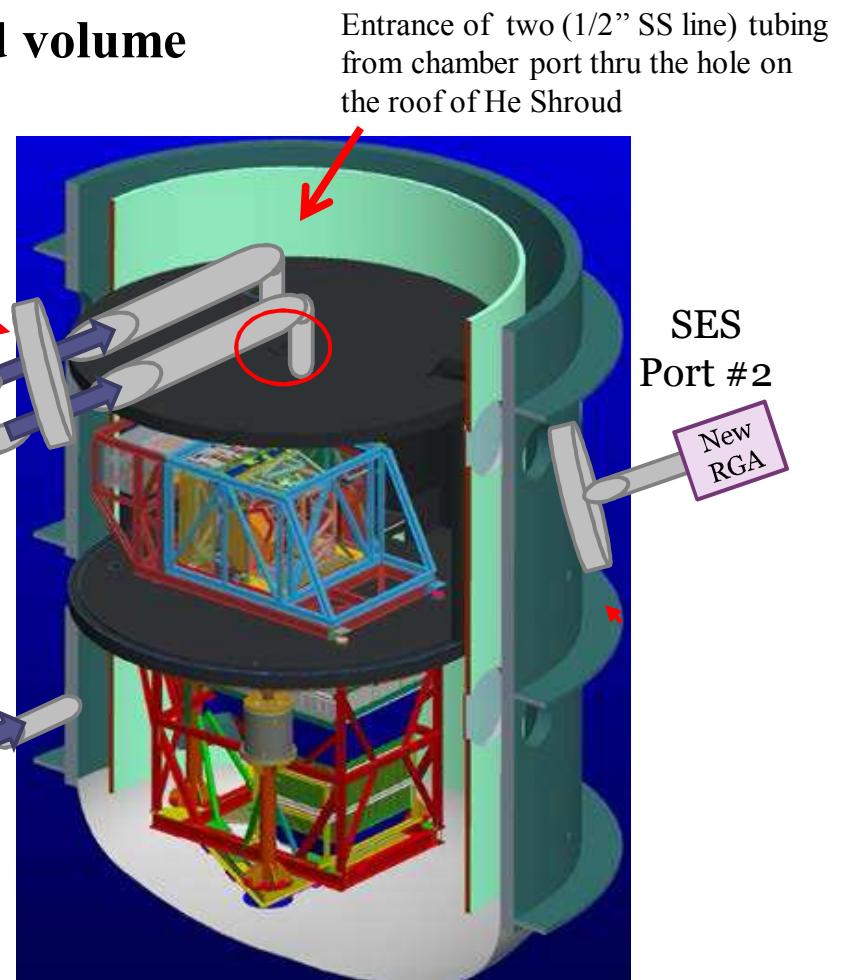
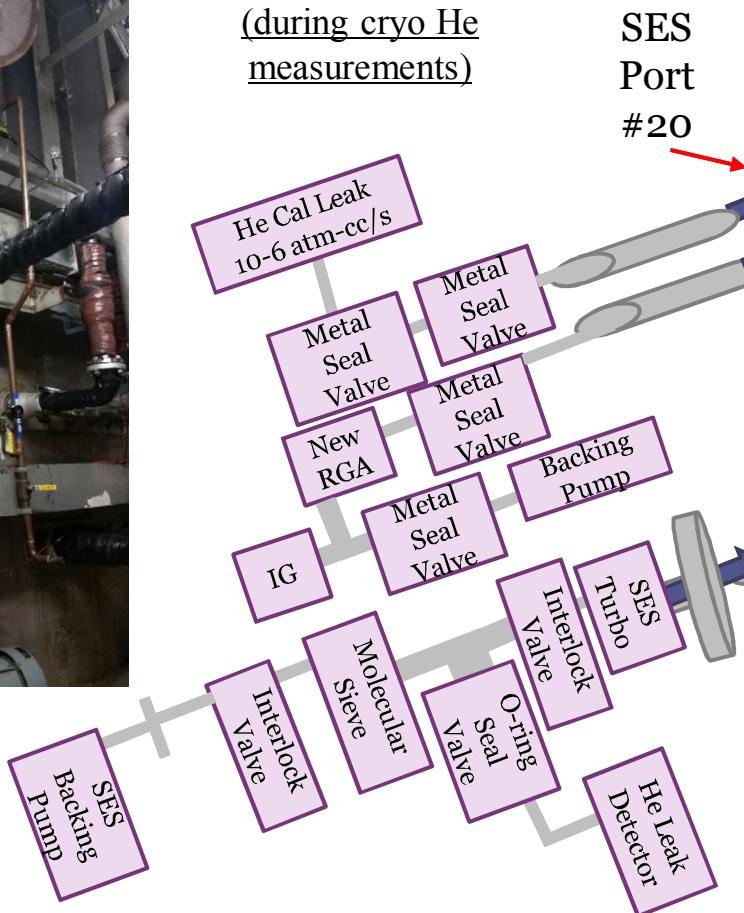


Notable Facility Changes Since CV2

2) New, calibrated RGA for helium shroud volume



Less sensitive configuration
(during cryo He
measurements)

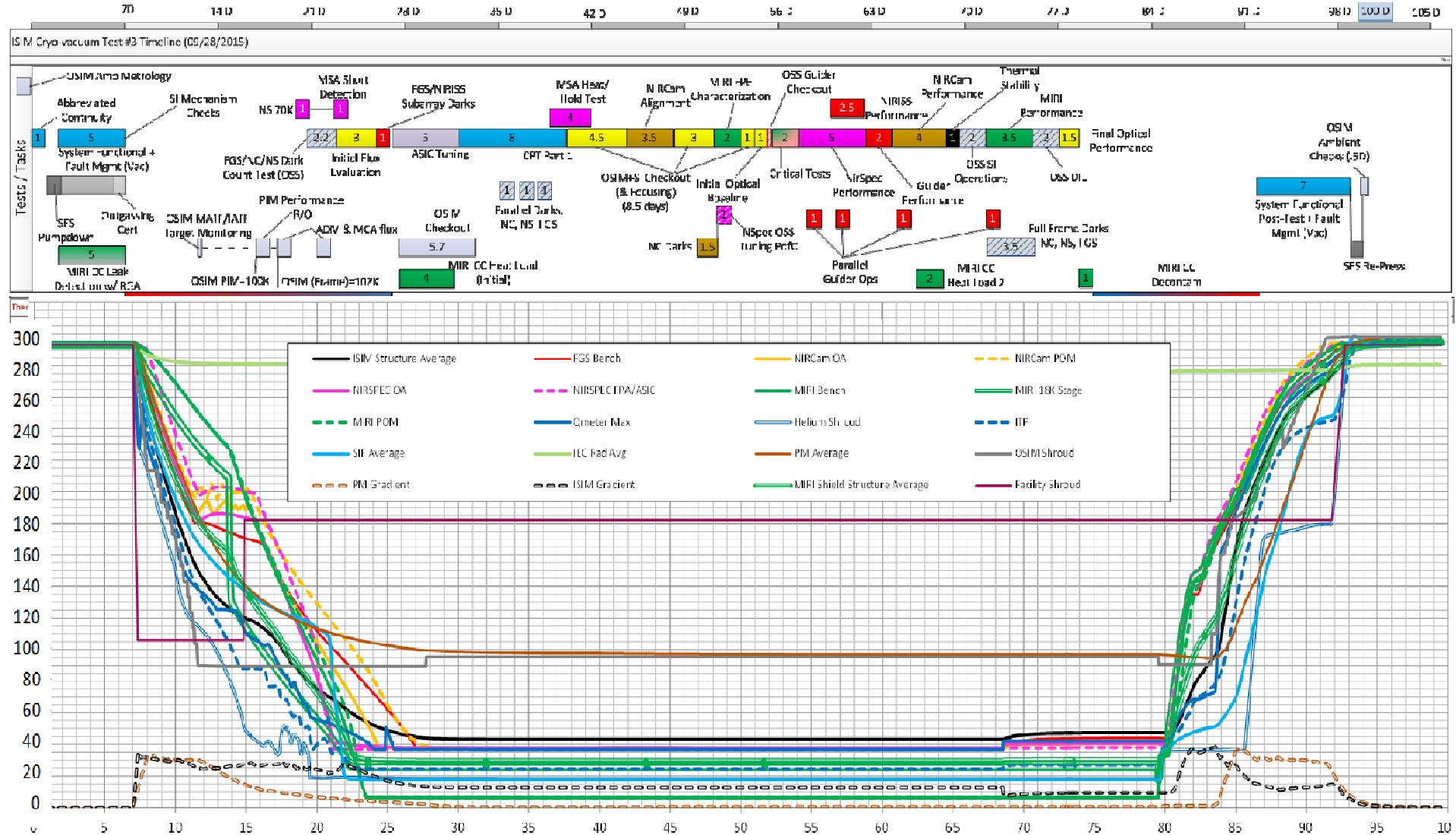


Notable Facility Changes Since CV2

- 1) Redundant micro ion gauge for IEC
 - 2) New, calibrated RGA for helium shroud volume
 - 3) New cryopumps
-
- Cryopump #2 made intermittent banging noises during CV2
 - Oil found on coldheads
 - Contaminated coldheads shipped to PHPK
 - PHPK investigated and replaced coldheads
 - Cryopump #4 & #6 were replaced
 - Cryopump #3 was rebuilt
 - Cryopumps started testing/check-out October 1, 2015: test for 13 days at cold pumping on itself



CV3 Test Profile



isi 1
000

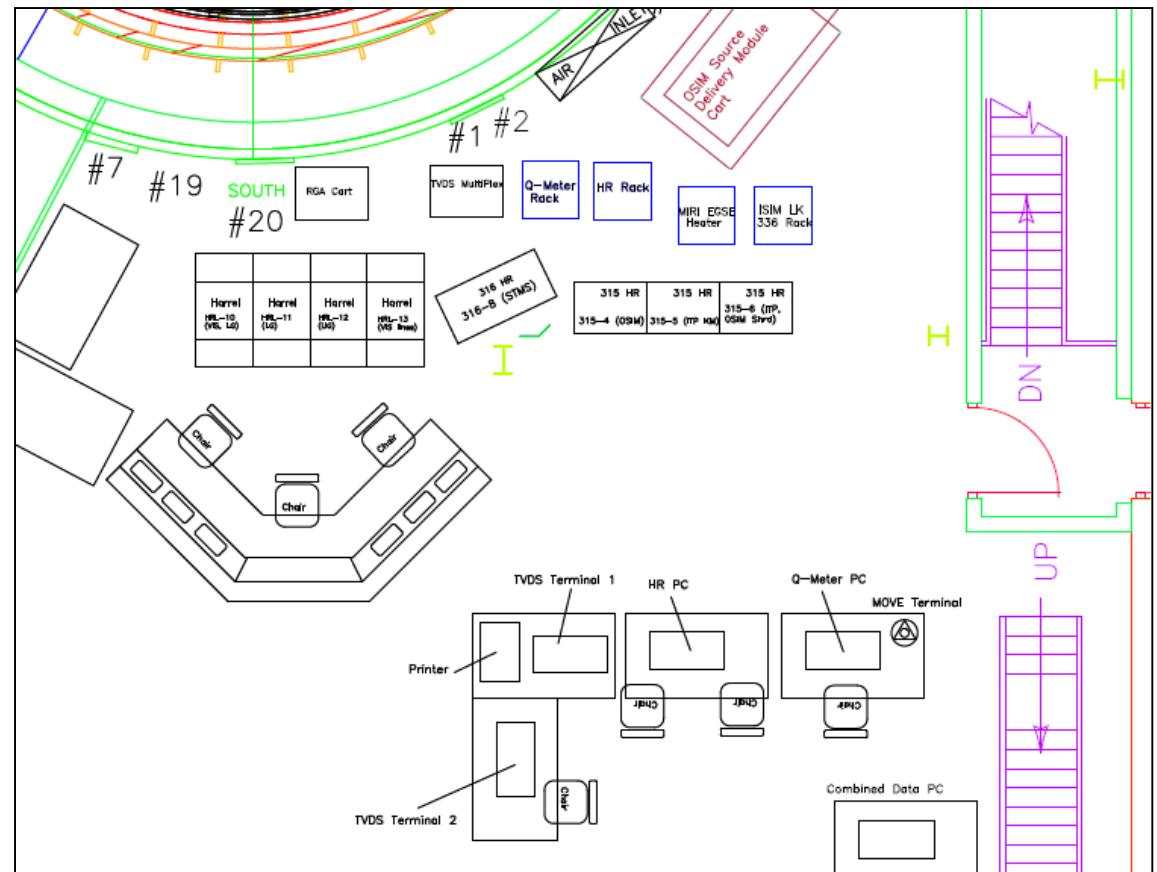
SES Facility LN2 Valve Failure

- An LN2 valve was discovered in a failed open position. This was flowing LN2 to the GN2 compressor. The excess LN2 needs to be dumped from the system, which requires securing the LN2 supply. This takes the chamber cryopumps off-line.
- Resolution: the excess LN2 was vented from the system while the chamber pressure was maintained, using only the chamber turbopump, at $\sim 2 \times 10^{-4}$ Torr. After the GN2 heat exchanger and LN2 lines were sufficiently drained on Saturday 10/31/15, the cryopump LN2 valve was made operational again. The facility is back to normal operation. The root cause of the GN2 heat exchanger flooding event was determined. The GN2 skid was shut-down and locked-out to allow a Proconex technician to troubleshoot and recalibrate a faulty positioner that indicated it had failed. In doing so, all the GN2 skid valves assumed their failed (open/close) safety position, and all pressure control loops were disabled. As a result, the heat exchanger GN2 inventory control loop which maintains a pressure of 60 to 70 PSIG was disabled allowing for the GN2 pressure in the heat exchanger to drop to 0 PSIG. Without there being pressure in the exchanger, the LN2 from the vent line filled up the exchanger. Once power was restored to the GN2 skid the pressure in the exchanger was reestablished without further incident.



Facility Preparation Status

- Data Acquisition
 - 3 TVDS stations set-up
 - 2 at SES
 - 1 in ICC for JWST (B29/R156)
 - Q-meter
 - Harness Radiator
 - TCR forms completed
 - Stand-alone systems in progress
 - CQCMs (x2)
 - RGAs (x2)
- Facility PMs have been completed, and none are scheduled for the duration of the CV3 test



Facility Preparation Status

- Documentation
 - Safety Evaluation Form
 - No changes from CV2
 - Request has been made to JWST to sign CV3 form, which will be added to the folder of safety evaluations for all the hardware in previous JWST tests
 - 549 procedure
 - Send out for review Tuesday, 10/13/15
 - Will collect signatures by Tuesday, 10/20/15
- Helium skid
 - Clean-up will start with pumping and purging when all hook-ups are completed
 - 20 He gas bottles being ordered for the SES
 - Rental generator contract for CV3 duration: arrive & install 10/13/15, electrically check-out and power transfer check on 10/15/15

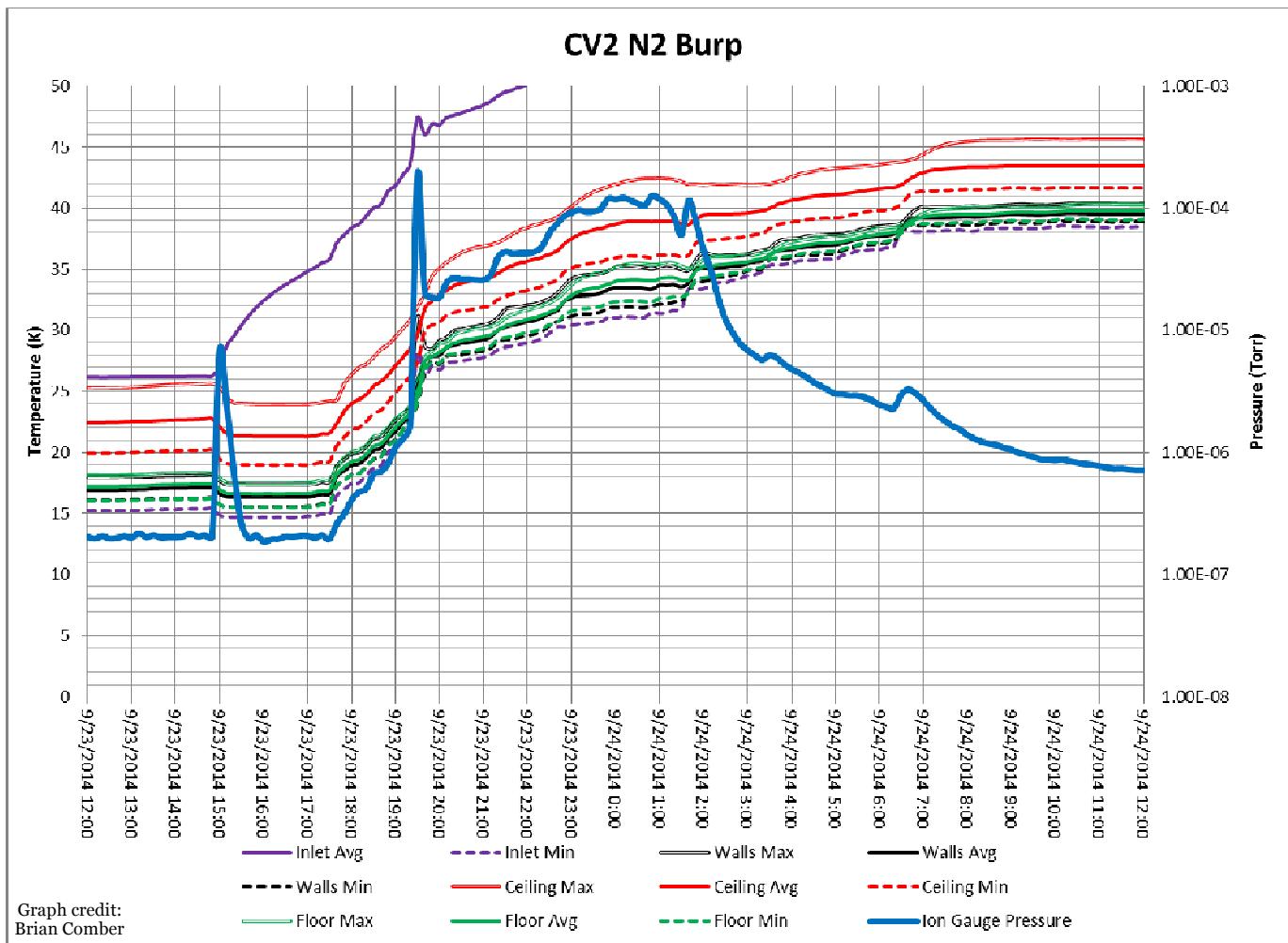


Top Facility-Related Risks for JWST

Description	Mitigations
Helium Leaks: MIRI Cooler heat load from CV1 was high & He measurements not sensitive enough in CV2	<ul style="list-style-type: none"> Standard leak check levels were made more stringent for CV2 <ul style="list-style-type: none"> Measured leaks to 10^{-9} Torr range Will use sniffer capable of measuring 10^{-11} Torr range to measure region that cannot pull vacuum to leak check Developed extensive calibrated RGA plan with MIRI team
Nitrogen leaks	<ul style="list-style-type: none"> Purge lines to SIs in He volume <ul style="list-style-type: none"> Leak check purge lines Disconnect, evacuate and cap after pumpdown Nitrogen shroud will operate in GN2 mode at steady state
Power outage	<ul style="list-style-type: none"> Will verify He skid UPS performance All JWST critical equipment on UPS
Chilled water outage	<ul style="list-style-type: none"> FMD 24/7 support Developed chilled water outage response plan & will communicate plan with JWST
New cryopumps	<ul style="list-style-type: none"> Test for 13 days



The Nitrogen (and Oxygen) Burp



Estimate of gas released: up to 700 g, or 0.65 torr, if released suddenly into the chamber → thermal effects would be significant



Compared to OSIM Nitrogen (& Oxygen) Burp

